International Communication System Interoperability Standards (ICSIS)

Draft C – February 2018

REVISION AND HISTORY

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PREFACE

INTERNATIONAL COMMUNICATION SYSTEM INTEROPERABILITY STANDARDS

This Communication System Interoperability standard is to ensure end-to-end compatibility, and interoperability between the Deep Space Gateway and Transport, visiting spacecraft and Earth, enabling on-orbit or surface crew operations and joint collaborative endeavors.

Configuration control of this document is the responsibility of the International Space Station (ISS) Multilateral Coordination Board (MCB), which is comprised of the international partner members of the ISS. The National Aeronautics and Space Administration (NASA) will maintain the International Communication System Interoperability Standard under Human Exploration and Operations Mission Directorate (HEOMD). Any revisions to this document will be approved by the ISS MCB.

INTERNATIONAL COMMUNICATION SYSTEM INTEROPERABILITY STANDARDS

CONCURRENCE

FEBRUARY 2018

Associate Administrator Human Exploration and Operations NASA	Date
Executive Director, Human Space Programs State Space Corporation “Roscosmos”	Date
Director of Human Spaceflight and Operations European Space Agency	Date
Director General, Space Exploration Canadian Space Agency	Date
Executive Director Japan Aerospace Exploration Agency	Date

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1.0 INTRODUCTION

This International Communications System Standard is the result of a collaboration by the International Space Station (ISS) membership to establish, interoperable interfaces, terminology, techniques, and environments to facilitate collaborative endeavors of space exploration in cis-Lunar and deep space environments.

Standards that are established and internationally recognized have been selected where possible to enable commercial solutions and a variety of providers. Increasing commonality while decreasing unique configurations has the potential to reduce the traditional barriers in space exploration: overall mass and volume required to execute a mission. Standardizing interfaces reduces the scope of the development effort and allows more focus on performance instead of form and fit.

The information within this document represents a set of parameters enveloping a broad range of conditions, which if accommodated in the system architecture support greater efficiencies, promote cost savings, and increase the probability of mission success. These standards are not intended to specify system details needed for implementation nor do they dictate design features behind the interface, specific requirements will be defined in unique documents.

1.1 PURPOSE AND SCOPE

The purpose of the International Communication System Interoperability Standards (ICSIS) Document is to define the functional, interface and performance standards necessary to support interoperable and compatible communications between the Deep Space Gateway (DSG) and Deep Space Transport (DST), ground infrastructure, other space and surface vehicles. Interoperable and compatible communications between space vehicles/systems, ground infrastructure, etc. is critical to the success of human exploration; it enables use of NASA, international partner, commercial and other assets interchangeably, decreases development and procurement costs and reduces operational and training complexity. Some of the key challenges to a communication systems as humans venture further out into space are:

a. the ability to operate over different mission phases and be compatible with different ground, surface and space-to-space interfaces;

b. the need to handle spectrum constraints, longer latencies and disruptions;

c. an evolving, highly networked architecture and its implications (dissimilar systems putting data onto a single link, quality of service, security and network management, etc.) and

d. system integration across multiple levels (infrastructure, multiple users, multiple control centers, etc.).

A common set of standards and interfaces at the different layers of the protocol stack is essential to addressing the above challenges while addressing size, weight and power constraints, and highly reliable operations. Components, systems, or vehicles delivered from multiple sources need to work together as an effective system to ensure success of actual missions. Such interoperability also enables partners to assist each other in emergency or contingency situations that can occur during Exploration.

The architecture, standards and protocols in the ICSIS document address both cislunar space as well as deep space missions (DSG and DST). However, the focus of this version of the document is on the cislunar space missions. The team is making every effort possible to ensure compatibility and extensibility of protocols and standards selected here to deep space missions. Future revisions of this document will include any modifications to the protocols and standards for deep space applicability. For example, the frequencies defined for the cislunar applications are per the near-Earth spectrum allocations. The frequencies for deep space excursions need to be added to be compliant with deep space spectrum allocations.

The communication standard makes use of existing Interagency Operations Advisory Group (IOAG) standard services and Consultative Committee on Space Data Systems (CCSDS) standards and protocols wherever possible. CCSDS is a multi-national forum for the development of communications and data systems standards for spaceflight and has worked over the years to develop, reach agreement and implement standards and protocols for space vehicles. In cases where the team identifies a gap in CCSDS standards for a particular application or link, they will work with the applicable CCSDS working group or other relevant standards development organization to standardize a commercial/industry standard or develop a new standard as appropriate.

1.2 RESPONSIBILITY AND CHANGE AUTHORITY

Any proposed changes to this standard by the participating partners of this agreement shall be brought forward to the Communication System Interoperability Standards committee for review.

Configuration control of this document is the responsibility of the International Space Station (ISS) Multilateral Coordination Board (MCB), which is comprised of the international partner members of the ISS. The National Aeronautics and Space Administration (NASA) will maintain the International Communication System Interoperability Standards Document under HEOMD Configuration Management. Any revisions to this document will be approved by the ISS MCB.

1.3 PRECEDENCE

This paragraph describes the hierarchy of document authority and identifies the document(s) that take precedence in the event of a conflict between content. Applicable documents include requirements that must be met. Any conflicts between a given value in this standard and the applicable document will be resolved at the ISS MCB.

Reference documents are either published research representing a specific point in time, or a document meant to guide work that does not have the full authority of an Applicable document. If a value in this document conflicts with a value in a referenced document, the value in this document takes precedent because the value here was selected based on new data or special constraints for the missions discussed.

2.0 DOCUMENTS

2.1 APPLICABLE DOCUMENTS

The following documents include specifications, models, standards, guidelines, handbooks, and other special publications. Applicable documents are levied by programs with authority to control system design or operations. The documents listed in this paragraph are applicable to the extent specified herein. Inclusion of applicable documents herein does not in any way supersede the order of precedence identified in Section 1.3 of this document.

Version numbers for DSG-Visiting Vehicle link applicable documents are explicitly called out to ensure compatibility and interoperability with Orion's S-band system. Version numbers for other Applicable documents will be added in as necessary to ensure compatibility and interoperability with ground stations and other users.

REC SFCG 32-2R1	Communication Frequency Allocations and Sharing in the Lunar Region
CCSDS 131.0-B-3	TM Synchronization and Channel Coding
CCSDS 734.2-B-1	Bundle Protocol Specification
CCSDS 734.1-B-1	Licklider Transmission Protocol (LTP) for CCSDS
CCSDS 732.0.B-3	AOS Space Data Link Protocol
CCSDS 401.0-B-26	Radio Frequency and Modulation Systems – Part 1
CCSDS 727.0-B-4	CCSDS File Delivery Protocol (CFDP) – Recommended Standard
CCSDS 735.1-B-1	Asynchronous Message Service (AMS)
CCSDS 414.1-B-2	Pseudo-Noise (PN) Ranging Systems
CCSDS 503.0-B-1	Tracking Data Message
FIPS PUB 197	Advanced Encryption Standard
NIST SP 800-38D	Recommendation for Block Cipher Modes of Operation: Galois/Counter Mode (GCM) and GMAC
CCSDS 355.0-B-1	Space Data Link Security Protocol
CCSDS 133.1-B-2	Encapsulation Service
CCSDS 211.1-B-4	Proximity-1 Space Link Protocol--Physical Layer

CCSDS 211.2-B-2	Proximity-1 Space Link Protocol--Coding and Synchronization Sublayer
CCSDS 211.0-B-5	Proximity-1 Space Link Protocol-Data Link Layer
CCSDS 301.0-B-4.	Time Code Formats
CCSDS 320.0-B-6.	CCSDS Global Spacecraft Identification Field Code Assignment Control Procedures
CCSDS 912.1-B-4.	Space Link Extension-- Space Link Extension--Forward CLTU Service Specification
CCSDS 911.1-B-4.	Space Link Extension--Return All Frames Service Specification
CCSDS 911.2-B-3.	Space Link Extension--Return Channel Frames Service Specification
CCSDS 922.1-B-1.	Cross Support Transfer Services--Monitored Data Service
CCSDS 921.1-B-1.	Cross Support Transfer Services—Specification Framework
CCSDS 506.1-B-1	Delta-DOR Raw Data Exchange Format
CCSDS 881.0-M-1	Spacecraft Onboard Interface Services – RFID Based Inventory Management Systems, Recommended Practice
RFC 791	Internet Protocol
RFC 8200	Internet Protocol version 6
CCSDS 766.2-B-1	Voice and Audio Communications
ANSI S3.2	Method For Measuring The Intelligibility Of Speech Over Communication Systems
ITU P.863	Perceptual objective listening quality assessment
CCSDS 766.1-B-1	Digital Motion Imagery
NASA STD-2822	Still and Motion Imagery Metadata Standard
CCSDS 352.0-B-1	CCSDS Cryptographic Algorithms
RFC 7242	Delay-Tolerant Networking TCP Convergence Layer Protocol
RFC 793	Transmission Control Protocol

RFC 768	User Datagram Protocol
RFC 6071	IP Security (IPSec) and Internet Key Exchange (IKE) Document Roadmap

2.2 REFERENCE DOCUMENTS

The following documents contain supplemental information to guide the user in the application of this document. These reference documents may or may not be specifically cited within the text of this document.

450-SNUG	Space Network Users' Guide (SNUG) https://sbir.gsfc.nasa.gov/sites/default/files/450-SNUG_V10.pdf
DSN 820-100	Deep Space Network Service Catalog https://deepspace.jpl.nasa.gov/advmiss/missiondesigndocs/#
DSN 810-005	DSN Telecommunications Link Design Handbook https://deepspace.jpl.nasa.gov/advmiss/missiondesigndocs/#
453-NENUG	Near Earth Network Users Guide https://sbir.gsfc.nasa.gov/sites/default/files/453-NENUG%20R2.pdf
CCSDS 506.0-M-1	Delta-Differential One Way Ranging (Delta-DOR) Operations https://public.ccsds.org/Pubs/506x0m1.pdf
CCSDS 901.1-M-1.	Space Communications Cross Support--Architecture Requirements Document https://public.ccsds.org/Pubs/901x1m1.pdf
IOAG Service Catalog #2	Interagency Operations Advisory Group Service Catalog #2 https://www.ioag.org/Public%20Documents/IOAG%20Service%20Catalog%20Two.v1.1-Approved.pdf

3.0 INTERNATIONAL COMMUNICATION SYSTEM INTEROPERABILITY STANDARDS

3.1 GENERAL

The goal of establishing standards and agreeing on assumptions is to maximize the interoperability of space vehicles, relays, and ground systems, etc. of future human spaceflight missions conducted as international partnerships. The ability of components, systems, or vehicles delivered from multiple sources to work together as an effective system is important to the success of actual missions. Such interoperability also enables partners to assist each other in emergency or contingency situations that can occur during Exploration. Good collaboration can make technology development and system maturation more efficient, by sharing the lessons learned and failures that drive requirements. Development of standards-based systems can also drive the costs to manufacture space systems lower, increasing the commercial and economic development potential of space and enabling more entities to participate. Using standard assumptions can also make development more efficient by making tests conducted by one partner relevant and valid to multiple partners.

Establishing a set of communication standards and designing it into the architecture, vehicles and supporting infrastructure is essential to ensure interoperability between communication end points to transfer data across multiple boundaries, networked communications and compatibility with partner assets (ground stations, relay satellites, etc.). The communication systems interface extends beyond the spacecraft's mold-line and an agreed to set of standards is the key to ensuring all parts of the interface "talk" with each other.

3.1.1 ENGINEERING UNITS OF MEASURE

This section clarifies nomenclature and units of measure as it pertains to space communication systems:

1. Near Earth Frequency Band (also known as Near Space Frequency Band) – Frequency bands used when space vehicle is within 2 million kilometers from Earth as allocated by International Telecommunication Union (ITU).
2. Deep Space Frequency Band – frequency bands used when space vehicle is beyond 2 million kilometers from Earth as allocated by ITU for space research use.
3. Bit numbering convention: the following convention is used to identify each bit in an N-bit field. The first bit in the field to be transmitted (i.e., the most left justified when drawing a figure) is defined to be 'Bit 0'; the following bit is defined to be 'Bit 1' and so on up to 'Bit N-1'. When the field is used to express a binary value (such as a counter), the Most Significant Bit (MSB) shall be the first transmitted bit of the field, i.e., 'Bit 0' (see figure 1-1).

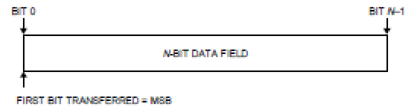


FIGURE 3.1.1-1 BIT NUMBERING CONVENTION

4. In accordance with standard data-communications practice, data fields are often grouped into 8- bit ‘words’ which conform to the above bit numbering convention - such an 8-bit word is called an ‘octet’. The numbering for octets within a data structure starts with 0.
5. By CCSDS convention, all ‘spare’ bits shall be permanently set to ‘0’.

3.2 INTERFACES

The Deep Space Gateway (DSG) communication system includes the necessary equipment to handle all data, audio and video communications within the spacecraft and interfaces with the Command & Data Handling (C&DH) system as well as all other in-space vehicles, lunar surface vehicles, and ground communication sites.

The terms relay, bent-pipe, and DSG-Ground are used in the interface definitions and standards. For DSG, the term “Relay” is defined as forward data from other DSG elements /payloads on to its destination, store data if link is not available; “Bent pipe” is where the header of the data is read and processed or modified, as needed, and (header + data) sent on to the correct user, actual user or payload data is not processed or modified; “DSG-Ground” is the term used for the Earth side of the interface that performs the required function(s). This could be ground station(s) (examples: Deep space network, near-earth network, etc.) or it could be a combination of ground station(s) and control center(s), etc. The ground station(s) used could be any of the NASA ground stations, an international partner ground station, a commercial or other agency ground station or a combination of one or more available ground stations.

The following sections describe the communication interfaces and provides the standards to be used to provide interoperability and compatibility.

The standards defined for the interfaces provide for the minimum capability required to support interoperable communications across that interface at the physical, space data link, and network layers plus at some select application layers. This allows for any ground station (or relay) to be able to communicate with the DSG during nominal or contingency operations. It is also expected that the DSG would be able to forward data between interfaces using either network layer routing or link layer switching. Therefore, if a DSG element implements an interface, then for all functions implemented on that interface, that element needs to, as a minimum, follow the respective standards defined in this document. For example, if an element has a high rate RF link with Earth, then it will need to follow the standards given in 3.2.2.2.2.1. The document is organized to facilitate this by defining all the requirements by function for each interface, thus making it “stand alone”.

3.2.1 DESCRIPTION OF INTERFACES

The DSG communication system includes:

- a DSG to Earth System that supports low rate data transfer as well as high rate data transfer between the DSG and Earth (direct-to-Earth or via relay); Standards are also provided for contingency communications link that supports spacecraft emergencies and contingencies. The IOAG is currently working on defining the process and standards for contingency communications. The contingency communications section will be finalized once the IOAG finalizes its recommendations.
- a DSG to Visiting Vehicle System that supports communications and radiometric tracking during rendezvous and proximity operations between the DSG and a visiting vehicle (VV);
- a DSG to Lunar Surface system that provides communications between the DSG and Lunar surface assets (direct link or via a relay);
- a Proximity communication system to provide core communications between Extravehicular activity (EVA) and DSG;
- a DSG Wireless communication system to support high rate communications between the Intra-vehicular activity (IVA), Extra-vehicular activity (EVA) and any other free flyers.

The standards for audio and video communications between DSG and endpoints as well as within DSG elements are defined in this document. There are hardline interfaces between the attached elements to allow data transfer (including audio and video) between the elements and this hardline interface is further defined in the International Avionic System Interoperability Standards (IASIS), and not covered in this document.

The DSG Communication interfaces are shown in Figure 3.2.1. As noted before, the DSG – Earth link could be a direct link or via a relay. Similarly, the DSG- Surface link could be a direct link or via a relay.

The detailed breakdown of data transferred between the DSG and Earth and between DSG and a visiting vehicle is given in Appendix D. Similar data would be transferred between the DSG and Lunar surface vehicles; EVA and other free-flyers. Functional data flow between the elements for a generic cislunar/planetary mission is given in Appendix E.

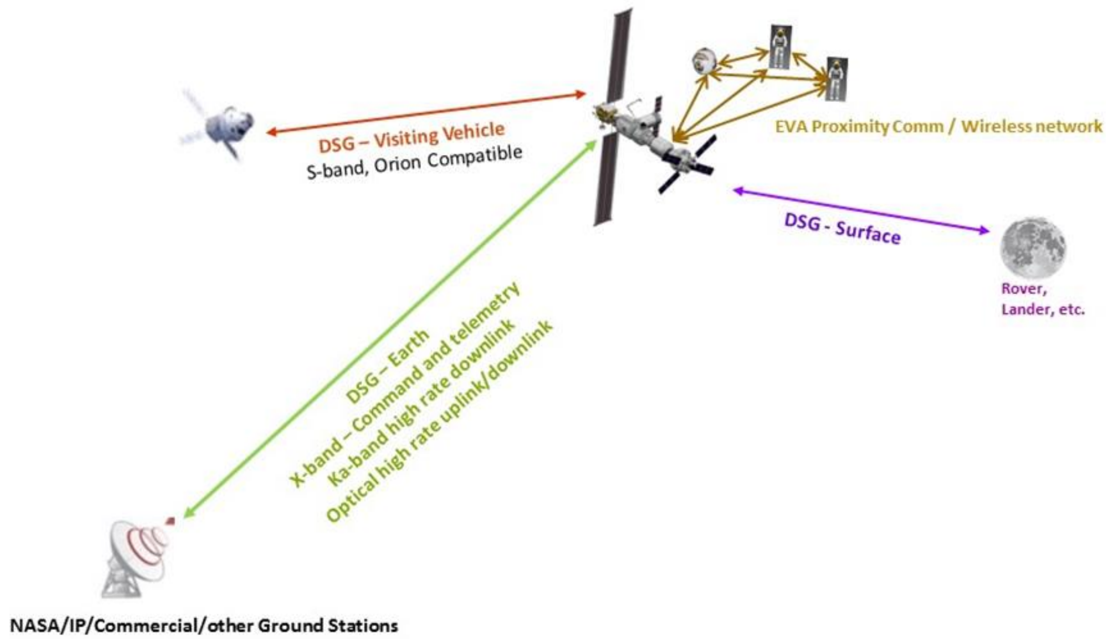


FIGURE 3.2-1 DEEP SPACE GATEWAY COMMUNICATION INTERFACES

3.2.2 INTERFACE STANDARDS

3.2.2.1 GENERAL

This section has communication interoperability requirements common to all DSG links.

3.2.2.1.1 SPECTRUM

Comm-1: DSG shall comply with radio frequency selection as defined in Recommendation SFCG 32-2R1, Communication Frequency Allocations and Sharing in the Lunar Region.

Rationale: Compliance with the Space Frequency Coordination Group recommendation on frequency use for the lunar region.

Comm-2: DSG shall comply with radio frequency allocation and conditions of assignment for frequency spectrum usage approved by the International Telecommunication Union (ITU) and respective ISS international partners' national spectrum usage regulations.

Rationale: Allocations of spectrum and constraints of its use is governed by each international partner's national regulations. For example, there is a European Regulation for allocated frequency selection and spectrum use (ERC Report 25) dictated by the ECC & CEPT from Europe. Allocations of frequency spectrum for U.S. Government systems, including NASA, are managed by the National Telecommunications and Information Administration (NTIA).

3.2.2.1.2 AUDIO

DSG audio communications will be used by the crew while on-board the DSG, during EVAs. Discussions with DSG-Ground, and personal communications with family and medical personnel. The requirements below are the minimum requirements to support interoperable audio communications.

Comm-3: DSG shall comply with Voice and Audio Communications, CCSDS 766.2-B-1 for all voice and audio exchanges.

Rationale: Crew on DSG will need voice and audio communications with DSG-Ground, Orion, Lunar assets, EVAs, etc. and having interoperable communications between them is essential to save cost, complexity and size weight and power.

Comm-4: DSG audio system shall be tested in accordance with ANSI S3.2 "Method for Measuring the Intelligibility of Speech over Communication Systems" for subjective speech intelligibility.

Rationale: DSG audio system needs to meet the intelligibility requirements to ensure that the audio and voice of different speakers over the system is comprehensible under different conditions.

Comm-5: DSG audio system shall be tested in accordance with ITU P.863 "Perceptual objective listening quality assessment", International standard for objective testing for speech quality.

Rationale: DSG audio system needs to meet the "speech quality" requirements to ensure system maintains a certain subjective quality or acceptability under different conditions.

3.2.2.1.3 VIDEO

DSG's video will be sent across multiple links for the purposes of engineering, science and public awareness. The crew will also use the video interface for personal communications with family and medical personnel. To ensure interoperability over these multiple interfaces and display conditions, DSG's video formats, interfaces, encapsulation, and transmission protocols need to be consistent with CCSDS 766.1-B-2 where practical depending on interoperability with avionics, human system interfaces, and other areas where video interoperates with other systems.

Comm-6: DSG shall comply with interface standards for compressed and non-compressed television signals specifically referenced in Digital Motion Imagery, CCSDS 766.1-B-2.

Rationale: DSG elements are likely to have camera and video systems from multiple sources that need to be interoperable. The CCSDS standard has already been agreed upon by multiple agencies and references video industry standards.

Comm-7: DSG shall acquire and distribute multiple resolutions and frame rates consistent with CCSDS 766.1-B-2.

Rationale: DSG elements video system will need to be scalable to support multiple operational scenarios where bandwidth is limited or communication links are limited. The CCSDS standard has already been agreed upon by multiple agencies and references multiple video resolutions and frame rates.

Comm-8: DSG shall provide compressed video signals with encapsulation and internet protocol transmission consistent with CCSDS 766.1-B-2.

Rationale: Uncompressed video far exceeds the bandwidth available between space craft and from space craft to ground via real-time communication links, therefore video will need to be compressed. Compressed video will need to be encapsulated for routing between space craft elements and to the ground. The CCSDS standard has already been agreed upon by multiple agencies and references multiple options for compression, encapsulation, and transmission, including DTN.

Comm-9: DSG should (TBD-7) provide metadata with imagery consistent with the protocols outlined in NASA STD 2822 where practical depending on interoperability with other systems.

Rationale: Data such as timing, camera location, and azimuth will be critical for monitoring operations, health and status of space craft and crew. The NASA Standard for imagery metadata references specific fields of data from NIST standards. CCSDS is working on a red book CCSDS red book 876.1-R-x, “XML Specification For Electronic Data Sheets” which should cover metadata. Once this standard gets approved and agreed to implementation by the international partners, the above requirement will be updated.

3.2.2.2 DSG – EARTH COMMUNICATION LINKS

The subsections below contain the communication standards specific to the DSG to Earth Links. The standards are selected to maximize interoperability/compatibility with the different ground networks/stations (including NASA, International partners, commercial, etc.).

3.2.2.2.1 COMMAND AND TELEMETRY COMMUNICATION LINKS

The communications link between DSG to Earth is used for sending:

1. commands, configuration updates, GNC state information, file uploads, audio, video, etc., from Earth to DSG; and
2. health and status data, engineering/science data, file downloads, audio, video, etc. from DSG to Earth.

Detailed list of data transferred between DSG and Earth during crewed and un-crewed operations of the DSG is given in Appendix D. This communication link uses X-band for uplink and downlink.

The rationale for selecting X-band is:

a. scalability to Mars and other deep space destinations;
b. power efficiency compared to S-band;
c. ability to handle higher data rates than S-band (its spectrum allocation allows for higher data rates than S-band); the bandwidth limitations on X-band is 10MHz (data rate is dependent on the modulation used (example 10Mbps for QPSK)).
d. better trade with antenna size/gain
e. supports radiometric tracking;
f. ground stations support both uplink and downlink (Ka-band uplink currently not supported by NASA or partners);
g. availability of space heritage, mature technology.

The summary of the standards for the Command and Telemetry link is given in Table 3.2.2.2-1.

TABLE 3.2.2.2-1 SUMMARY OF STANDARDS FOR DSG COMMAND AND TELEMETRY LINK

	Frequency Bands[1]	Modulation[2]	Coding[3]	Space Data Link Protocol	Space Data Link Security	Ranging
Earth to DSG Nominal: ≤ 10 Msps	7190-7235 MHz	PCM/PM/NRZ-L - Modulation on residual carrier	LDPC[3, 6]: • Coding rates: - $^{1}/_{2}$, $^{2}/_{3}$, $^{4}/_{5}$, $^{7}/_{8}$ • Codeblock size: - 2048 octets (for rates $^{1}/_{2}$, $^{2}/_{3}$, $^{4}/_{5}$) - 1020 octets (for rate $^{7}/_{8}$)	AOS[4], USLP[5] • AOS frame size: - 2048 octets and 64 bit ASM (for rates $^{1}/_{2}$, $^{2}/_{3}$, $^{4}/_{5}$) - 1020 octets and 32 bit ASM (for rate $^{7}/_{8}$)	CCSDS Space Data Link Security Protocol[8]	CCSDS PN[7] • Non-regenerative. • Ranging chip rate: ≤ 4 Mcps. Simultaneous data and PN ranging for both modulation options.
DSG to Earth Nominal: ≤ 4 Msps	8450-8500 MHz	PCM/PM/NRZ-L - Modulation on residual carrier	LDPC[3,6]: • Coding rates: - $^{1}/_{2}$, $^{2}/_{3}$, $^{4}/_{5}$, $^{7}/_{8}$ • Codeblock size: - 2048 octets (for rates $^{1}/_{2}$, $^{2}/_{3}$, $^{4}/_{5}$) - 1020 octets (for rate $^{7}/_{8}$)	AOS[4], USLP[5] • AOS frame size: - 2048 octets and 64 bit ASM (for rates $^{1}/_{2}$, $^{2}/_{3}$, $^{4}/_{5}$) - 1020 octets and 32 bit ASM (for rate $^{7}/_{8}$)	CCSDS Space Data Link Security Protocol[8]	CCSDS PN[7] • Non-regenerative. • Ranging chip rate: ≤ 4 Mcps. Simultaneous data and PN ranging for both modulation options.

1. SFCG 32-2R1 Communication Frequency Allocations and Sharing in the Lunar Region.
2. CCSDS 401.0-B-27 Radio Frequency and Modulation Systems--Part 1: Earth Stations and Spacecraft. Blue Book.
3. CCSDS 131.0-B-3 TM Synchronization and Channel Coding. Blue Book.
4. CCSDS 732.0-B-3 AOS Space Data Link Protocol. Blue Book.
5. CCSDS 732.1-R-3.1 Unified Space Data Link Protocol. Red Book. November 2017, currently undergoing publication.
6. CCSDS (TBD Reference) Coding & Synchronization Sub-layer High Rate Uplink Protocol for AOS & USLP.

7. CCSDS 414.1-B-2 Pseudo-Noise (PN) Ranging Systems. Blue Book.
8. CCSDS 355.0-B-1 Space Data Link Security Protocol. Blue Book.

3.2.2.2.1.1 FREQUENCY

Comm-10: DSG shall use 8450-8500 MHz (X-band) frequency band to transmit signals to DSG-Ground (Earth) on the Command and Telemetry link.

Rationale: Use of near-Earth X-band is compliant with ITU and CCSDS/SFCG recommendations. X-band is used for TT&C links since its allocation allows for data rates up to 10 Mbps (using QPSK modulation) from DSG to Earth.

Comm-11: DSG-Ground shall use 8450-8500 MHz (X-band) frequency band to receive signals from DSG on the Command and Telemetry link.

Rationale: Use of near-Earth X-band is compliant with ITU and CCSDS/SFCG recommendations. X-band is used for TT&C links since its allocation allows for data rates up to 10 Mbps (using QPSK modulation) from DSG to Earth

Comm-12: DSG shall use 7190-7235 MHz (X-band) frequency band to receive signals from DSG-Ground (Earth) on the Command and Telemetry link.

Rationale: Use of near-Earth X-band is compliant with ITU and CCSDS/SFCG recommendations. X-band is used for TT&C links since its allocation allows for data rates up to 1 Mbps from Earth to DSG.

Comm-13: DSG-Ground shall use 7190-7235 MHz (X-band) frequency band to transmit signals to DSG on the Command and Telemetry link.

Rationale: Use of near-Earth X-band is compliant with ITU and CCSDS/SFCG recommendations. X-band is used for TT&C links since its allocation allows for data rates up to 1 Mbps from Earth to DSG.

Comm-14: DSG shall use 7190-7235 MHz (X-band) frequency band to receive signals from DSG-Ground on the Command and Telemetry link.

Rationale: Use of near-Earth X-band is compliant with ITU and CCSDS/SFCG recommendations. X-band is used for TT&C links since its allocation allows for data rates up to 1 Mbps from Earth to DSG.

3.2.2.2.1.2 MODULATION ON THE COMMAND AND TELEMETRY LINK

Comm-15: DSG shall implement BPSK and OQPSK modulation schemes as described in *Radio Frequency and Modulation Systems--Part 1: Earth Stations and Spacecraft,* Section 2, CCSDS 401.0-B-27.

Rationale: BPSK is selected because of the need for providing ranging. OQPSK is bandwidth efficient.

Comm-16: DSG shall implement PCM/PM/NRZ-L with modulation on residual carrier to transmit signals to DSG-Ground as described in *Radio Frequency and*

Modulation Systems--Part 1: Earth Stations and Spacecraft, Section 2, CCSDS 401.0-B-27, on the Command and Telemetry link.

Rationale: PCM/PM/NRZ-L with modulation on residual carrier provides interoperability between DSG and NASA/IP/etc. ground stations, provides spectrum efficiency and meets spectrum constraints imposed by SFCG and NTIA.

Comm-17: DSG-Ground shall implement PCM/PM/NRZ-L with modulation on residual carrier signals to receive signals from DSG as described in *Radio Frequency and Modulation Systems--Part 1: Earth Stations and Spacecraft,* Section 2, CCSDS 401.0-B-27, on the Command and Telemetry link.

Rationale: PCM/PM/NRZ-L with modulation on residual carrier provides interoperability between DSG and NASA/IP/etc. ground stations, provides spectrum efficiency and meets spectrum constraints imposed by SFCG and NTIA.

Comm-18: DSG-Ground shall implement PCM/PM/NRZ-L with modulation on sub-carrier to transmit signals to DSG as described in *Radio Frequency and Modulation Systems--Part 1: Earth Stations and Spacecraft,* Section 2, CCSDS 401.0-B-27, on the Command and Telemetry link.

Rationale: PCM/PM/NRZ-L with modulation on sub-carrier provides interoperability between DSG and NASA/IP/etc. ground stations, provides spectrum efficiency and meets spectrum constraints imposed by SFCG and NTIA.

Comm-19: DSG shall implement PCM/PM/NRZ-L with modulation on sub-carrier signals to receive signals from DSG-Ground as described in *Radio Frequency and Modulation Systems--Part 1: Earth Stations and Spacecraft,* Section 2, CCSDS 401.0-B-27, on the Command and Telemetry link.

Rationale: PCM/PM/NRZ-L with modulation on sub-carrier provides interoperability between DSG and NASA/IP/etc. ground stations, provides spectrum efficiency and meets spectrum constraints imposed by SFCG and NTIA.

3.2.2.2.1.3 CODING AND SYNCHRONIZATION ON THE COMMAND AND TELEMETRY LINK

Comm-20: DSG shall be able to enable or disable forward error correction (FEC) to support contingency operations with DSG-Ground on the Command and Telemetry link

Rationale: DSG needs to able to enable or disable FEC to support contingency and other operational scenarios.

Comm-21: DSG-Ground shall be able to enable or disable forward error correction (FEC) to support contingency operations with DSG on the Command and Telemetry link

Rationale: DSG needs to able to enable or disable FEC to support contingency and other operational scenarios.

Comm-22: DSG shall use CCSDS Low Density Parity Codes, rate ½, rate $^{2}/_{3}$, rate $^{4}/_{5}$, or rate $^{7}/_{8}$ for encoding data to DSG-Ground as defined in Section 7, TM Synchronization and Channel Coding, CCSDS 131.0-B-3, on the Command and Telemetry link.

Rationale: Coding gain provided by LDPC codes is ~2dB more than that provided by concatenated Reed-Solomon/convolutional codes. Can implement one, two, three or all four of the above LDPC codes based on data rates and other system needs/constraints.

Comm-23: DSG-Ground shall use CCSDS Low Density Parity Codes, rate ½, rate $^{2}/_{3}$, rate $^{4}/_{5,}$ and rate $^{7}/_{8}$ for decoding data from DSG as defined in Section 7, TM Synchronization and Channel Coding. CCSDS 131.0-B-3, on the Command and Telemetry link.

Rationale: Coding gain provided by LDPC codes is ~2dB more than that provided by concatenated Reed-Solomon/convolutional codes.

Comm-24: DSG-Ground shall use CCSDS Low Density Parity Codes, rate ½, rate $^{2}/_{3}$, rate $^{4}/_{5,}$ and rate $^{7}/_{8}$ for encoding data to DSG as defined in Section 7, TM Synchronization and Channel Coding CCSDS 131.0-B-3, on the Command and Telemetry link.

Rationale: Coding gain provided by LDPC codes is ~2dB more than that provided by concatenated Reed-Solomon/convolutional codes.

Note: Forward error correction (FEC) codes defined in CCSDS 131.0-B-3 TM Synchronization and Channel Coding Blue book are currently only applicable to spacecraft-to-Earth links. However, in view of the symmetric property of the AOS space data link protocol, the CCSDS LDPC code can be applied to the AOS frames over DSG-to-Earth link. In order to reduce the burden on the links, we are using it over DSG-Ground-to-DSG links.

Comm-25: DSG shall use CCSDS Low Density Parity Codes, rate ½, rate $^{2}/_{3}$, rate $^{4}/_{5,}$ or rate $^{7}/_{8}$ for decoding data from DSG-Ground as defined in Section 7, TM Synchronization and Channel Coding CCSDS 131.0-B-3, on the Command and Telemetry link.

Rationale: Coding gain provided by LDPC codes is ~2dB more than that provided by concatenated Reed-Solomon/convolutional codes. Can implement one, two, three or all four of the above LDPC codes based on data rates and other system needs/constraints.

Comm-26: DSG shall apply the Attached Sync Marker (ASM) defined in Section 9, *TM Synchronization and Channel Coding* CCSDS 131.0-B-3, to transmitted frames to DSG-Ground per Table 3.2.2.2-2 on the Command and Telemetry link.

Rationale: Use of the 64-bit CCSDS frame sync pattern identified as ASM for rate ½, rate $^{2}/_{3}$, or rate $^{4}/_{5}$ and the 32-bit CCSDS frame sync pattern identified for rate $^{7}/_{8}$ *LDPC Coded Data provides the receiver the ability to synchronize at the start of a FEC code block frame and will ensure interoperability between DSG and NASA/IP ground stations. Using the same 64 bit/32 bit ASM for non-FEC coded block frames will maintain a common frame structure for all coded and uncoded frames, which will reduce Program implementation complexity and costs.*

Comm-27: DSG-Ground shall use the Attached Sync Marker (ASM) defined in Section 9, *TM Synchronization and Channel Coding* CCSDS 131.0-B-3, for synchronization of received frames from DSG per Table 3.2.2.2-2 on the Command and Telemetry link.

Rationale: Use of the 64-bit CCSDS frame sync pattern identified as ASM for rate ½, rate $^{2}/_{3}$, or rate $^{4}/_{5}$ and the 32-bit CCSDS frame sync pattern identified for rate $^{7}/_{8}$ *LDPC Coded Data provides the receiver the ability to synchronize at the start of a FEC code block frame and will ensure interoperability between DSG and NASA/IP ground stations. Using the same 64 bit/32 bit ASM for non-FEC coded block frames will maintain a common frame structure for all coded and uncoded frames, which will reduce Program implementation complexity and costs.*

TABLE 3.2.2.2-2 ASM MARKER FOR SELECTED LDPC CODES

	Rate ½ LDPC Code	*Rate $^{2}/_{3}$ LDPC Code*	*Rate $^{4}/_{5}$ LDPC Code*	*Rate $^{7}/_{8}$ LDPC Code*
ASM Length	*64 bits*	*64 bits*	*64 bits*	*32 bits*
ASM Pattern (hex)	034776C7272895B0	034776C7272895B0	034776C7272895B0	1ACFFC1D

Comm-28: DSG-Ground shall apply the Attached Sync Marker (ASM) defined in Section 9, *TM Synchronization and Channel Coding* CCSDS 131.0-B-3, to transmitted frames to DSG per Table 3.2.2.2-2 on the Command and Telemetry link.

Rationale: Use of the 64-bit CCSDS frame sync pattern identified as ASM for rate ½, rate $^{2}/_{3}$, or rate $^{4}/_{5}$ and the 32-bit CCSDS frame sync pattern identified for rate $^{7}/_{8}$ *LDPC Coded Data provides the receiver the ability to synchronize at the start of a FEC code block frame and will ensure interoperability between DSG and NASA/IP ground stations. Using the same 64 bit/32 bit ASM for non-FEC coded block frames will maintain a common frame structure for all coded and uncoded frames, which will reduce Program implementation complexity and costs.*

Comm-29: DSG shall use the Attached Sync Marker (ASM) defined in Section 9, *TM Synchronization and Channel Coding* [CCSDS 131.0-B-3](), for synchronization of received frames from DSG-Ground per Table 3.2.2.2-2 on the Command and Telemetry link.

Rationale: Use of the 64-bit CCSDS frame sync pattern identified as ASM for rate ½, rate $^2/_3$, or rate $^4/_5$ and the 32-bit CCSDS frame sync pattern identified for rate $^7/_8$ *LDPC Coded Data provides the receiver the ability to synchronize at the start of a FEC code block frame and will ensure interoperability between DSG and NASA/IP ground stations. Using the same 64 bit/32 bit ASM for non-FEC coded block frames will maintain a common frame structure for all coded and uncoded frames, which will reduce Program implementation complexity and costs.*

Comm-30: DSG shall use bit randomization techniques in accordance with CCSDS 131.0-B-3 for randomization of transmitted data streams to DSG-Ground on the Command and Telemetry link.

Rationale: Use of bit randomization techniques as specified in CCSDS 131.0-B-2 will ensure the proper bit synchronization process and interoperability between DSG and NASA/IP ground stations

Comm-31: DSG-Ground shall use bit derandomization techniques in accordance with CCSDS 131.0-B-3 for derandomization of received data streams from DSG on the Command and Telemetry link.

Rationale: Use of bit derandomization techniques as specified in CCSDS 131.0-B-2 will ensure the proper bit synchronization process and interoperability between DSG and NASA/IP ground stations.

Comm-32: DSG-Ground shall use bit randomization techniques in accordance with CCSDS 131.0-B-3 for randomization of transmitted data streams to DSG on the Command and Telemetry link.

Rationale: Use of bit randomization techniques as specified in CCSDS 131.0-B-2 will ensure the proper bit synchronization process and interoperability between DSG and NASA/IP ground stations

Comm-33: DSG shall use bit derandomization techniques in accordance with CCSDS 131.0-B-3 for derandomization of received data streams from DSG-Ground on the Command and Telemetry link.

Rationale: Use of bit derandomization techniques as specified in CCSDS 131.0-B-2 will ensure the proper bit synchronization process and interoperability between DSG and NASA/IP ground stations.

Comm-34: DSG shall use Non-Return-to-Zero-Level (NRZ-L) encoding for transmission of data streams to DSG-Ground on the Command and Telemetry link.

Rationale: NRZ-L is required to allow LDPC FEC codes to operate at maximum efficiency, producing the highest possible amount of coding gain.

NRZ-L symbol L format encoding has better E_b/N_o performance than differential symbol format encoding like Non-Return-to-Zero-Mark (NRZ-M). Phase ambiguity resolution will be resolved by using a frame Attached Sync Marker (ASM) rather than using differential encoding like NRZ-M.

Comm-35: DSG-Ground shall use Non-Return-to-Zero-Level (NRZ-L) encoding for transmission of data streams to DSG on the Command and Telemetry link.

Rationale: NRZ-L is required to allow LDPC FEC codes to operate at maximum efficiency, producing the highest possible amount of coding gain. NRZ-L symbol L format encoding has better E_b/N_o performance than differential symbol format encoding like Non-Return-to-Zero-Mark (NRZ-M). Phase ambiguity resolution will be resolved by using a frame Attached Sync Marker (ASM) rather than using differential encoding like NRZ-M.

Comm-36: DSG shall use the ASM for resolution of symbol phase ambiguity of received data streams from DSG-Ground on the Command and Telemetry link.

Rationale: Phase ambiguity resolution will be resolved by using a frame ASM rather than using differential symbol format encoding like Non-Return-to-Zero-Mark (NRZ-M) since NRZ-L is needed to allow LDPC FEC codes to operate at maximum efficiency. NRZ-L also has better E_b/N_o performance than differential encoding like NRZ-M.

Comm-37: DSG-Ground shall use the ASM for resolution of symbol phase ambiguity of received data streams from DSG on the Command and Telemetry link.

Rationale: Phase ambiguity resolution will be resolved by using a frame ASM rather than using differential symbol format encoding like Non-Return-to-Zero-Mark (NRZ-M) since NRZ-L is needed to allow LDPC FEC codes to operate at maximum efficiency. NRZ-L also has better E_b/N_o performance than differential encoding like NRZ-M.

3.2.2.2.1.4 RANGING ON THE COMMAND AND TELEMETRY LINK

Comm-38: DSG shall support radiometric tracking (PN ranging) as defined in Pseudo-Noise (PN) Ranging Systems, CCSDS 414.1-B-2 on the Command and Telemetry link.

Rationale: DSG needs to support radiometric tracking/ranging to support GN&C since there are currently no "GPS" like capabilities. Note: NASA-DSN will only support CCSDS PN ranging using k & l parameter values that equate to $\leq$ 4 Mchips/sec. DSN currently does its own version of PN ranging that is not CCSDS-compliant. DSN does have a requirement to upgrade to CCSDS PN ranging in their baseline but haven't determined when the upgrade will be implemented. Requiring DSG to implement CCSDS PN Ranging for interoperability gives DSN a mission-driven date.

Comm-39: DSG shall use non-regenerative ranging with DSG-Ground using a PN chip rate of 4 ≤ Mcps as defined in Pseudo-Noise (PN) Ranging Systems, CCSDS 414.1-B-2 on the Command and Telemetry link.

Rationale: DSG needs to support radiometric tracking/ranging to support GN&C since there are currently no "GPS" like capabilities. The ranging mode selected provides for simultaneous data with ranging. Note: NASA-DSN will only support CCSDS PN ranging using k & l parameter values that equate to ≤ 4 Mchips/sec. DSN currently does its own version of PN ranging that is not CCSDS-compliant. DSN does have a requirement to upgrade to CCSDS PN ranging in their baseline but haven't determined when the upgrade will be implemented. Requiring DSG to implement CCSDS PN Ranging for interoperability gives DSN a mission-driven date.

Comm-40: DSG-Ground shall use non-regenerative ranging with a chip rate of ≤ 4 Mcps with DSG to provide radiometric tracking (PN ranging) as defined in Pseudo-Noise (PN) Ranging Systems, CCSDS 414.1-B-2 on the Command and Telemetry link.

Rationale: DSG needs to support radiometric tracking/ranging to support GN&C since there are currently no "GPS" like capabilities. The ranging mode selected provides for simultaneous data with ranging. Note: NASA-DSN will only support CCSDS PN ranging using k & l parameter values that equate to ≤ 4 Mchips/sec. DSN currently does its own version of PN ranging that is not CCSDS-compliant. DSN does have a requirement to upgrade to CCSDS PN ranging in their baseline but haven't determined when the upgrade will be implemented. Requiring DSG to implement CCSDS PN Ranging for interoperability gives DSN a mission-driven date.

Comm-41: DSG shall use Tracking Data Message to support tracking as defined in Tracking Data Message. CCSDS 503.0-B-1 on the Command and Telemetry link.

Rationale: This is the standard for radiometric data formats. It is relevant to the ground station-to-user MOC interface.

Comm-42: DSG shall use Delta-DOR Raw data exchange format (TBR-2) as defined in CCSDS 506.1-B-1**,** Delta-DOR Raw Data Exchange Format to exchange radiometric data with DSG-Ground on the Command and Telemetry link.

Rationale: DSG needs to support radiometric tracking/ranging to support GN&C since there are currently no "GPS" like capabilities. Note: NASA-DSN will only support CCSDS PN ranging using k & l parameter values that equate to ≤ 4 Mchips/sec. DSN currently does its own version of PN ranging that is not CCSDS-compliant. DSN does have a requirement to upgrade to CCSDS PN ranging in their baseline but haven't determined when the upgrade will be implemented. Requiring DSG to implement CCSDS PN Ranging for interoperability gives DSN a mission-driven date.

3.2.2.2.1.5 DATA LINK LAYER FRAMING ON THE COMMAND AND TELEMETRY LINK

Comm-43: DSG shall transmit data streams to DSG-Ground using data link framing as defined in CCSDS Advanced Orbiting Systems (AOS) Space Data Link Protocol, CCSDS 732.0-B-3 on the Command and Telemetry link.

Rationale: CCSDS 732.0-B-3 provides the structure for frame construction. Need to follow this standard to ensure interoperability between DSG and NASA/IP ground stations.

NOTE: CCSDS is working to baseline the Unified Space Link Protocol (USLP). Once the USLP blue book is baselined and all partners agree to implement it, the above standard (CCSDS 732.0-B-3) will be updated with the USLP blue book.

Comm-44: DSG-Ground shall receive data streams from DSG using data link framing as defined in CCSDS Advanced Orbiting Systems (AOS) Space Data Link Protocol, CCSDS 732.0-B-3 on the Command and Telemetry link.

Rationale: CCSDS 732.0-B-3 provides the structure for frame construction. Need to follow this standard to ensure interoperability between DSG and NASA/IP ground stations.

NOTE: CCSDS is working to baseline the Unified Space Link Protocol (USLP). Once the USLP blue book is baselined and all partners agree to implement it, this standard will be updated with the USLP blue book.

Comm-45: DSG-Ground shall transmit data streams to DSG using data link framing as defined in CCSDS Advanced Orbiting Systems (AOS) Space Data Link Protocol, CCSDS 732.0-B-3 on the Command and Telemetry link.

Rationale: CCSDS 732.0-B-3 provides the structure for frame construction. Need to follow this standard to ensure interoperability between DSG and NASA/IP ground stations.

NOTE: CCSDS is working to baseline the Unified Space Link Protocol (USLP). Once the USLP blue book is baselined and all partners agree to implement it, the above standard (CCSDS 732.0-B-3) will be updated with the USLP blue book.

Comm-46: DSG shall receive data streams from DSG-Ground using data link framing as defined in CCSDS Advanced Orbiting Systems (AOS) Space Data Link Protocol, CCSDS 732.0-B-3 on the Command and Telemetry link.

Rationale: CCSDS 732.0-B-3 provides the structure for frame construction. Need to follow this standard to ensure interoperability between DSG and NASA/IP ground stations.

NOTE: CCSDS is working to baseline the Unified Space Link Protocol (USLP). Once the USLP blue book is baselined and all partners agree to implement it, this standard will be updated with the USLP blue book.

3.2.2.2.1.6 NETWORK LAYERS AND ABOVE ON THE COMMAND AND TELEMETRY LINK

The sub-sections below address the standards for the layers of the protocol stack at the network layer and above, as illustrated in Figure 3. DSG will transmit and receive data using network-based applications, with some exceptions for contingency operations. These applications will use either DTN or IP protocols to allow communications over the data link layer options described above and over multiple hops.

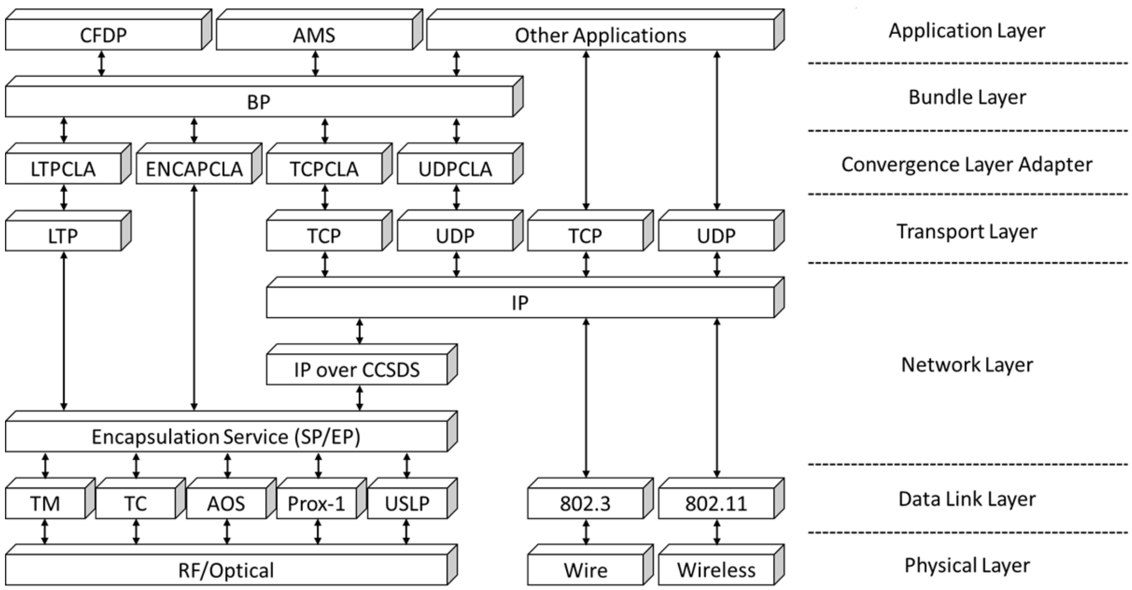


FIGURE 3.2-2 PROTOCOL STACK – OPTIONS

This document currently does not include any terrestrial interfaces in support of DTN and IP – this is part of the forward work defined in Section 4.0. The CCSDS Space Communications Cross Support--Architecture Requirements Document (CCSDS 901.1-M-1.) provides a reference for that topic. A particular element may not need to implement all the applications listed in the following sections to support its mission objectives. However, for any applications in these sections that the element implements, it needs to follow the standards called out in the respective sections.

3.2.2.2.1.6.1 NETWORK LAYER

Comm-47: DSG shall transmit and receive data streams using the CCSDS Encapsulation Service as defined in CCSDS 133.1-B-2 when communicating over CCSDS Data Link Layer Protocols with DSG-Ground on the Command and Telemetry link.

Rationale: CCSDS Data Link Layers are designed to carry either CCSDS Space Packets or Encapsulation Packets. The Encapsulation Service provides the compatibility between the higher layer data units and the CCSDS Data Link Layers.

Comm-48: DSG-Ground shall transmit and receive data streams using the CCSDS Encapsulation Service as defined in CCSDS 133.1-B-2 when communicating over CCSDS Data Link Layer Protocols with DSG on the Command and Telemetry link.

Rationale: CCSDS Data Link Layers are designed to carry either CCSDS Space Packets or Encapsulation Packets. The Encapsulation Service provides the compatibility between the higher layer data units and the CCSDS Data Link Layers.

Comm-49: DSG shall transmit and receive IP packets using the CCSDS IP over CCSDS standard CCSDS 702.1-B-1 when using IP packets over CCSDS Data Link Layers with DSG-Ground on the Command and Telemetry link.

Rationale: This allows IP packet use interoperability over CCSDS links.

Comm-50: DSG –Ground shall transmit and receive IP packets using the CCSDS IP over CCSDS standard CCSDS 702.1-B-1 when using IP packets over CCSDS Data Link Layers with DSG on the Command and Telemetry link.

Rationale: This allows IP packet use interoperability over CCSDS links

Comm-51: DSG shall use IP as specified in IPv4 (RFC 791) or IPv6 (RFC 8200) (TBR-16) as a network layer with DSG-Ground on the Command and Telemetry link.

Rationale: IP provides for network layer services over interfaces that have low delay (under 5 sec (TBD)) and an expectation of real time end-to-end connectivity. Use of IP allows for maximum leverage of terrestrial networking developments under appropriate circumstances. IPv4-based technology is widely available in the commercial market. IPv6-only stack provides advantages such as increased security and more efficient routing. IPv6 technology is not as readily available.

Comm-52: DSG-Ground shall use IP as specified in IPv4 (RFC 791) or IPv6 (RFC 8200) (TBR-16) as a network layer with DSG on the Command and Telemetry link.

Rationale: IP provides for network layer services over interfaces that have low delay (under 5 sec (TBD)) and an expectation of real time end-to-end connectivity. Use of IP allows for maximum leverage of terrestrial networking developments under appropriate circumstances. IPv4-based technology is widely available in the commercial market. IPv6-only stack provides advantages such as increased security and more efficient routing. IPv6 technology is not as readily available.

3.2.2.2.1.6.2 TRANSPORT LAYER

Comm-53: DSG shall (TBR-7) implement Licklider Transmission Protocol (LTP) as specified in CCSDS Licklider Transmission Protocol for CCSDS, CCSDS 734.1-B-1 on the Command and Telemetry link.

Rationale: LTP is a reliable point-to-point transport protocol, over which the Bundle Protocols will run. LTP is not expected to be used for all links, but was designed for long-haul links with high delay.

Comm-54: DSG shall implement Transmission Control Protocol (TCP) as specified in RFC 793 on the Command and Telemetry link.

Rationale: TCP is a reliable transport protocol for use on IP networks.

Comm-55: DSG shall implement User Datagram Protocol (UDP) as specified in RFC 768 on the Command and Telemetry link.

Rationale: UDP provides best effort transport protocol for use on IP networks.

3.2.2.2.1.6.3 BUNDLE AND BUNDLE CONVERGENCE LAYER

Comm-56: DSG shall implement Delay Tolerant Networking Bundle Protocol as specified in CCSDS Bundle Protocol Specification, CCSDS 734.2-B-1 on the Command and Telemetry link.

Rationale: Provide lunar network and inter-planetary network functionality, e.g., network addressing, routing, and QoS management, in end-to-end communications environment of intermittent connectivity. When functioning as a relay, the DSG must have the capability to multiplex/demultiplex capability to deal with multiple data streams from multiple sources over heterogeneous links.

Comm-57: DSG should (TBR-18) implement the CCSDS standard “Streamlined Bundle Security Protocol” (DRAFT CCSDS 734.5-B-1) to secure DTN standard data bundles.

Rationale: Securing DTN bundles for transport is essential.

Comm-58: When DSG data links are not using secure DTN bundling, they should (TBR-19) provide for the option to implement Internet Protocol Security (IPSec) over IP links. IPSec is specified in RFC 6071.

Rationale: Application of IPSec to these data flows is strongly recommended to reduce mission risk when the data flows are not secured by the DTN Bundle security protocol.

Comm-59: DSG shall implement the Licklider Transmission Protocol Convergence Layer Adapter as specified in CCSDS 734.2-B-1 on the Command and Telemetry.

Rationale: In cases when Bundle Protocol is used over long delay or environments not conducive to IP-based convergence layers, LTP can provide reliable delivery. LTP may optionally be used over UDP [TBR]

Comm-60: DSG shall implement the Encapsulation Convergence Layer Adapter as specified in CCSDS 734.2-B-1 on the Command and Telemetry link.

Rationale: In circumstances when Bundle Protocol is used without a transport layer protocol, the encapsulation convergence layer adapter will *allow bundles to be directly encapsulated and transmitted over CCSDS link layer protocols.*

Comm-61: DSG should implement the TCP Convergence Layer Adapter as specified in RFC 7242 (TBR-17) on the Command and Telemetry link.

Rationale: When a hop between DTN nodes is carried over an IP network, the TCP convergence layer will provide reliable delivery of bundles. RFC 7242 is in the experimental stage and not a finalized standard.

Comm-62: DSG should implement the UDP Convergence Layer Adapter as specified in CCSDS 734.2-B-1 on the Command and Telemetry link.

Rationale: When a hop between DTN nodes is carried over an IP network, the UDP convergence layer will provide unreliable delivery of bundles. Addition of LTP over the UDP convergence layer may be used to provide reliable bundle delivery.

3.2.2.2.1.6.4 APPLICATION LAYER

Comm-63: All applications transferring data over this interface shall use either DTN Bundle Protocol or IP as specified above on the Command and Telemetry link.

Rationale: This will allow all data flows to be routable by intermediate nodes. Any application that expects to flow data to and from Earth either directly or relayed should use BP to accommodate delays or end-to-end link availability. Though IP may work in some cislunar cases, use of BP will allow the application to also function in deep space cases.

Comm-64: DSG shall use CCSDS File Delivery Protocol Class 1 and Class 2 as defined in *CCSDS File Delivery Protocol (CFDP),* CSDS 727.0-B-4 transmit and receive application layer files on the Command and Telemetry link.

Rationale: Provide reliable, accountable transfer of files.

Comm-65: DSG should (TBR-14) use asynchronous message service (AMS) as defined in Asynchronous Message Service (AMS) CCSDS 735.1-B-1 to transmit and receive messages on the Command and Telemetry link.

Rationale: provides a standard, reusable infrastructure for the exchange of information among data system modules in a manner that is simple to use, highly automated, flexible, robust, scalable, and efficient.

3.2.2.2.1.7 SECURITY ON THE COMMAND AND TELEMETRY LINK

The following define the security standards to ensure interoperability for the Command and Telemetry DSG to DSG-Ground links. The actual links & data to be protected, security & key management, etc. will be based on the International Partner agreement on security policies for the Program(s).

Comm-66: DSG shall implement CCSDS Cryptographic Algorithms, *CCSDS 352.0-B-1*, Advanced Encryption Standard (AES), for encryption/decryption of data exchanges with DSG-Ground on the Command and Telemetry link.

Rationale: AES is the algorithm of choice for Federal Information Systems per FIPS PUB 197.

Comm-67: DSG-Ground shall implement CCSDS Cryptographic Algorithms, *CCSDS 352.0-B-1*, Advanced Encryption Standard (AES), for encryption/decryption of data exchanges with DSG on the Command and Telemetry link.

Rationale: AES is the algorithm of choice for Federal Information Systems per FIPS PUB 197.

Comm-68: DSG shall implement the Advanced Encryption Standard specifically the Galois Counter Mode (AES-GCM) algorithm per NIST SP 800-38D, with 256-bit keys, 96-bit Initialization Vectors (IVs), and with authentication tag lengths of 128 bits truncated to 64 bits for data exchanges with DSG-Ground on the Command and Telemetry link. *Programs need to assess the level of Security Information Assurance and Risks for non-command and control links, and shall select an appropriate AES mode commensurate with those risks, and implement MOU/MOA agreements to handle applicable circumstances*.

Rationale: The use of AES-GCM is an efficient implementation for encryption and authentication of data and information exchanges.

Comm-69: DSG-Ground shall implement the Advanced Encryption Standard specifically the Galois Counter Mode (AES-GCM) algorithm per NIST SP 800-38D, with 256-bit keys, 96-bit Initialization Vectors (IVs), and with authentication tag lengths of 128 bits truncated to 64 bits for data exchanges with DSG on the Command and Telemetry link. *Programs need to assess the level of Security Information Assurance and Risks for non-command and control links, and shall select an appropriate AES mode commensurate with those risks, and implement MOU/MOA agreements to handle applicable circumstances*.

Rationale: The use of AES-GCM is an efficient implementation for encryption and authentication of data and information exchanges.

Comm-70: DSG shall implement link layer security as specified by CCSDS 355.0-B-1, Space Data Link Security Protocol for data exchanges with DSG-Ground on the Command and Telemetry link.

Rationale: Use CCSDS standards to ensure interoperability and compatibility.

Comm-71: DSG-Ground shall implement link layer security as specified by CCSDS 355.0-B-1, Space Data Link Security Protocol for data exchanges with DSG on the Command and Telemetry link.

Rationale: Use CCSDS standards to ensure interoperability and compatibility.

Comm-72: DSG shall implement authentication as specified by *CCSDS 355.0-B-1* CCSDS Cryptographic Algorithms for data exchanges with DSG-Ground on the Command and Telemetry link.

Rationale: DSG needs to support authentication in addition to encryption.

Comm-73: DSG-Ground shall implement authentication as specified by *CCSDS 355.0-B-1* CCSDS Cryptographic Algorithms for data exchanges with DSG on the Command and Telemetry link.

Rationale: DSG needs to support authentication in addition to encryption.

Comm-74: DSG shall be able to enable or disable encryption to support contingency operations with DSG-Ground on the Command and Telemetry link.

Rationale: DSG needs to be able to turn off encryption to support spacecraft recovery, contingency modes, etc.

Comm-75: DSG-Ground shall be able to enable or disable encryption to support contingency operations with DSG on the Command and Telemetry link.

Rationale: DSG-Ground needs to be able to turn off encryption to support spacecraft recovery, contingency modes, etc

Comm-76: DSG shall employ key management techniques as defined in TBD-1 with DSG-Ground on the Command and Telemetry link. (TBD-1 could be SDLS Extended Procedures standard (draft CCSDS 355.1-B-1) as noted below)

Rationale: This requirement ensures that keys are managed in an interoperable manner.

Note: CCSDS is working on the SDLS Extended Procedures standard (CCSDS 355.1-B-1)*. Once the standard is baselined and all partners agree to implement it, this standard will be updated with the Symmetric Key Management blue book.*

Comm-77: DSG-Ground shall employ key management techniques as defined in TBD-1 with DSG on the Command and Telemetry link. (TBD-1 could be SDLS Extended Procedures standard (draft CCSDS 355.1-B-1) as noted below)

Rationale: This requirement ensures that keys are managed in an interoperable manner.

Note: CCSDS is working on the SDLS Extended Procedures standard (CCSDS 355.1-B-1)*. Once the standard is baselined and all partners agree to implement it, this standard will be updated with the Symmetric Key Management blue book.*

3.2.2.2.2 HIGH RATE COMMUNICATION LINKS

This subsection defines standards for high rate data transfer between DSG and DSG-Ground. Ka-band and Optical communication links are selected for this application. Ka-band is considered in accordance with CCSDS/SFCG recommendations since it is bandwidth efficient and there is no need for a ranging channel on the high rate link. The X-band Command and Telemetry link supports ranging needs. NASA and partner ground stations currently only support Ka-band downlink and do not support Ka-band uplink capability – however, having a high rate uplink is necessary to support human exploration and it is anticipated that the ground stations will be upgraded to provide this capability. A minimum set of standards for the Ka-band uplink is also provided in this section to provide the implementers some guidance on what a Ka-band forward link might support, These links are marked with a TBR to indicate that this still need to be resolved.

Optical links are selected for their power efficiency i.e. ability to transfer large volumes of data over long distances at lower power than Ka-band as well as providing both a high rate uplink and downlink.

3.2.2.2.2.1 HIGH RATE RF LINK

A summary of the standards for the DSG to DSG-Ground high rate RF link is provided in Table 3.2.2.2-3.

TABLE 3.2.2.2-3 SUMMARY OF STANDARDS FOR DSG HIGH RATE RF LINK

	Frequency Bands[1]	Modulation[2]	Coding[3]	Space Data Link Protocol	Space Data Link Security	Ranging
Earth to DSG High rate Nominal > 10 Msps	22.55-23.15 GHz	• OQPSK - Modulation on suppressed carrier	LDPC[3, 6]: • Coding rates: - $^1/_2$, $^2/_3$, $^4/_5$, $^7/_8$ • Codeblock size: - 2048 octets (for rates $^1/_2$, $^2/_3$, $^4/_5$) - 1020 octets (for rate $^7/_8$)	AOS[4], USLP[5] • AOS frame size: - 2048 octets and 64 bit ASM (for rates $^1/_2$, $^2/_3$, $^4/_5$) - 1020 octets and 32 bit ASM (for rate $^7/_8$)	CCSDS Space Data Link Security Protocol[8]	None
DSG to Earth High rate Nominal > 4 Msps	25.5-27.0 GHz	• OQPSK Modulation on suppressed carrier	LDPC[3,6]: • Coding rates: - $^1/_2$, $^2/_3$, $^4/_5$, $^7/_8$ • Codeblock size: - 2048 octets (for rates $^1/_2$, $^2/_3$, $^4/_5$) - 1020 octets (for rate $^7/_8$)	AOS[4], USLP[5] • AOS frame size: - 2048 octets and 64 bit ASM (for rates $^1/_2$, $^2/_3$, $^4/_5$) - 1020 octets and 32 bit ASM (for rate $^7/_8$)	CCSDS Space Data Link Security Protocol[8]	None

9. SFCG 32-2R1 Communication Frequency Allocations and Sharing in the Lunar Region.
10. CCSDS 401.0-B-27 Radio Frequency and Modulation Systems--Part 1: Earth Stations and Spacecraft. Blue Book.
11. CCSDS 131.0-B-3 TM Synchronization and Channel Coding. Blue Book.
12. CCSDS 732.0-B-3 AOS Space Data Link Protocol. Blue Book.
13. CCSDS 732.1-R-3.1 Unified Space Data Link Protocol. Red Book. November 2017, currently undergoing publication.
14. CCSDS (TBD Reference) Coding & Synchronization Sub-layer High Rate Uplink Protocol for AOS & USLP.
15. CCSDS 414.1-B-2 Pseudo-Noise (PN) Ranging Systems. Blue Book.
16. CCSDS 355.0-B-1 Space Data Link Security Protocol. Blue Book.

3.2.2.2.2.1.1 FREQUENCY FOR HIGH RATE RF LINKS

Comm-78: DSG shall use 25.5 - 27 GHz (Ka-band) frequency band to transmit signals to DSG-Ground on the High Rate RF link.

Rational: Use of near-Earth Ka-band is compliant with ITU and CCSDS/SFCG recommendations. Ka-band is used for high rate downlinks since its allocation allows for very high data rates.

Comm-79: DSG-Ground shall use 25.5 - 27 GHz (Ka-band) frequency band to receive signals from DSG on the High Rate RF link.

Rational: Use of near-Earth Ka-band is compliant with ITU and CCSDS/SFCG recommendations. Ka-band is used for high rate downlinks since its allocation allows for very high data rates.

Comm-80: DSG-Ground shall use 22.55 – 23.15 GHz (Ka-band) frequency band to transmit signals to DSG on the High Rate RF link.

Rational: Use of near-Earth Ka-band is compliant with ITU and CCSDS/SFCG recommendations. Ka-band is used for high rate downlinks since its allocation allows for very high data rates.

Comm-81: DSG shall use 22.55 – 23.15 GHz (Ka-band) frequency band to receive signals from DSG-Ground on the High Rate RF link.

Rational: Use of near-Earth Ka-band is compliant with ITU and CCSDS/SFCG recommendations. Ka-band is used for high rate downlinks since its allocation allows for very high data rates.

3.2.2.2.2.1.2 MODULATION HIGH RATE RF LINKS

Comm-82: DSG shall implement OQPSK with modulation on suppressed carrier to transmit signals to DSG-Ground as described in *Radio Frequency and Modulation Systems--Part 1: Earth Stations and Spacecraft,* Section 2, CCSDS 401.0-B-27, on the High Rate RF link.

Rationale: OQPSK with modulation on suppressed carrier provides spectral efficiency and interoperability between DSG and NASA/IP/etc. ground stations, provides spectrum efficiency and meets spectrum constraints imposed by SFCG and NTIA.

Comm-83: DSG-Ground shall implement OQPSK with modulation on suppressed carrier to receive signals from DSG as described in *Radio Frequency and Modulation Systems--Part 1: Earth Stations and Spacecraft,* Section 2, CCSDS 401.0-B-27, on the High Rate RF link.

Rationale: OQPSK with modulation on suppressed carrier provides spectral efficiency and interoperability between DSG and NASA/IP/etc. ground stations, provides spectrum efficiency and meets spectrum constraints imposed by SFCG and NTIA.

Comm-84: DSG-Ground shall implement OQPSK with modulation on suppressed carrier to transmit signals to DSG as described in *Radio Frequency and Modulation Systems--Part 1: Earth Stations and Spacecraft,* Section 2*,* CCSDS 401.0-B-27, on the High Rate RF link. (TBR-15)

Rationale: OQPSK with modulation on suppressed carrier provides spectral efficiency and interoperability between DSG and NASA/IP/etc. ground stations, provides spectrum efficiency and meets spectrum constraints imposed by SFCG and NTIA.

Comm-85: DSG shall implement OQPSK with modulation on suppressed *carrier* to receive signals from DSG-Ground as described in *Radio Frequency and Modulation Systems--Part 1: Earth Stations and Spacecraft,* Section 2*,* CCSDS 401.0-B-27, on the High Rate RF link.(TBR-15)

Rationale: OQPSK with modulation on suppressed carrier provides spectral efficiency and interoperability between DSG and NASA/IP/etc. ground stations, provides spectrum efficiency and meets spectrum constraints imposed by SFCG and NTIA.

3.2.2.2.2.1.3 CODING AND SYNCHRONIZATION HIGH RATE RF LINKS

Comm-86: DSG shall use CCSDS Low Density Parity Codes, rate ½, rate $^{2}/_{3}$, rate $^{4}/_{5}$, or rate $^{7}/_{8}$ for encoding data to DSG-Ground as defined in Section 7, TM Synchronization and Channel Coding CCSDS 131.0-B-3, on the High Rate RF link.

Rationale: Coding gain provided by LDPC codes is ~2dB more than that provided by concatenated Reed-Solomon/convolutional codes. Can implement one, two, three or all four of the above LDPC codes based on data rates and other system needs/constraints.

Comm-87: DSG-Ground shall use CCSDS Low Density Parity Codes, rate ½, rate $^{2}/_{3}$, rate $^{4}/_{5}$, and rate $^{7}/_{8}$ for decoding data from DSG as defined in Section 7, TM Synchronization and Channel Coding CCSDS 131.0-B-3on the High Rate RF link.

Rationale: Coding gain provided by LDPC codes is ~2dB more than that provided by concatenated Reed-Solomon/convolutional codes.

Comm-88: DSG-Ground shall use CCSDS Low Density Parity Codes, rate ½, rate $^{2}/_{3}$, rate $^{4}/_{5}$, and rate $^{7}/_{8}$ for encoding data to DSG as defined in Section 7, TM Synchronization and Channel Coding CCSDS 131.0-B-3 on the High Rate RF link. (TBR-15)

Rationale: Coding gain provided by LDPC codes is ~2dB more than that provided by concatenated Reed-Solomon/convolutional codes.

Note: Forward error correction (FEC) codes defined in CCSDS 131.0-B-3 TM Synchronization and Channel Coding Blue book are currently only applicable to spacecraft-to-Earth links. However, in view of the symmetric property of the AOS space data link protocol, the CCSDS LDPC code can be applied to the AOS frames over DSG-to-Earth link. In order to reduce the burden on the links, we are using it over DSG-Ground-to-DSG links.

Comm-89: DSG shall use CCSDS Low Density Parity Codes, rate ½, rate $^{2}/_{3}$, rate $^{4}/_{5}$, or rate $^{7}/_{8}$ for decoding data from DSG-Ground as defined in Section 7, TM Synchronization and Channel Coding CCSDS 131.0-B-3 on the High Rate RF link.

Rationale: Coding gain provided by LDPC codes is ~2dB more than that provided by concatenated Reed-Solomon/convolutional codes. Can implement one, two, three or all four of the above LDPC codes based on data rates and other system needs/constraints.

Comm-90: DSG shall apply the Attached Sync Marker (ASM) defined in Section 9, *TM Synchronization and Channel Coding* CCSDS 131.0-B-3, to transmitted frames to DSG-Ground per Table 3.2.2.2-2 on the High Rate RF link.

Rationale: Use of the 64-bit CCSDS frame sync pattern identified as ASM for rate ½, rate $^{2}/_{3}$, or rate $^{4}/_{5}$ and the 32-bit CCSDS frame sync pattern identified for rate $^{7}/_{8}$ *LDPC Coded Data provides the receiver the ability to synchronize at the start of a FEC code block frame and will ensure interoperability between DSG and NASA/IP ground stations. Using the same 64 bit/32 bit ASM for non-FEC coded block frames will maintain a common frame structure for all coded and uncoded frames, which will reduce Program implementation complexity and costs.*

Comm-91: DSG-Ground shall use the Attached Sync Marker (ASM) defined in Section 9, *TM Synchronization and Channel Coding* CCSDS 131.0-B-3, for synchronization of received frames from DSG per Table 3.2.2.2-2 on the High Rate RF link.

Rationale: Use of the 64-bit CCSDS frame sync pattern identified as ASM for rate ½, rate $^{2}/_{3}$, or rate $^{4}/_{5}$ and the 32-bit CCSDS frame sync pattern identified for rate $^{7}/_{8}$ *LDPC Coded Data provides the receiver the ability to synchronize at the start of a FEC code block frame and will ensure interoperability between DSG and NASA/IP ground stations. Using the same 64 bit/32 bit ASM for non-FEC coded block frames will maintain a common frame structure for all coded and uncoded frames, which will reduce Program implementation complexity and costs.*

Comm-92: DSG-Ground shall apply the Attached Sync Marker (ASM) defined in Section 9, *TM Synchronization and Channel Coding* CCSDS 131.0-B-3, to transmitted frames to DSG per Table 3.2.2.2-2 on the High Rate RF link. (TBR-15)

Rationale: Use of the 64-bit CCSDS frame sync pattern identified as ASM for rate ½, rate $^{2}/_{3}$, or rate $^{4}/_{5}$ and the 32-bit CCSDS frame sync pattern identified for rate $^{7}/_{8}$ *LDPC Coded Data provides the receiver the ability to* *synchronize at the start of a FEC code block frame and will ensure interoperability between DSG and NASA/IP ground stations. Using the same 64 bit/32 bit ASM for non-FEC coded block frames will maintain a common frame structure for all coded and uncoded frames, which will reduce Program implementation complexity and costs.*

Comm-93: DSG shall use the Attached Sync Marker (ASM) defined in Section 9, *TM Synchronization and Channel Coding* CCSDS 131.0-B-3 for synchronization of received frames from DSG-Ground per Table 3.2.2.2-2 on the High Rate RF link. (TBR-15)

Rationale: Use of the 64-bit CCSDS frame sync pattern identified as ASM for rate ½, rate $^{2}/_{3}$, or rate $^{4}/_{5}$ and the 32-bit CCSDS frame sync pattern identified for rate $^{7}/_{8}$ *LDPC Coded Data provides the receiver the ability to synchronize at the start of a FEC code block frame and will ensure interoperability between DSG and NASA/IP ground stations. Using the same 64 bit/32 bit ASM for non-FEC coded block frames will maintain a common frame structure for all coded and uncoded frames, which will reduce Program implementation complexity and costs.*

Comm-94: DSG shall use bit randomization techniques in accordance with CCSDS 131.0-B-3 for randomization of transmitted data streams to DSG-Ground on the High Rate RF link.

Rationale: Use of bit randomization techniques as specified in CCSDS 131.0-B-2 will ensure the proper bit synchronization process and interoperability between DSG and NASA/IP ground stations

Comm-95: DSG-Ground shall use bit derandomization techniques in accordance with CCSDS 131.0-B-3 for derandomization of received data streams from DSG on the High Rate RF link.

Rationale: Use of bit derandomization techniques as specified in CCSDS 131.0-B-2 will ensure the proper bit synchronization process and interoperability between DSG and NASA/IP ground stations.

Comm-96: DSG-Ground shall use bit randomization techniques in accordance with CCSDS 131.0-B-3 for randomization of transmitted data streams to DSG on the High Rate RF link. (TBR-15)

Rationale: Use of bit randomization techniques as specified in CCSDS 131.0-B-2 will ensure the proper bit synchronization process and interoperability between DSG and NASA/IP ground stations

Comm-97: DSG shall use bit derandomization techniques in accordance with CCSDS 131.0-B-3 for derandomization of received data streams from DSG-Ground on the High Rate RF link. (TBR-15)

Rationale: Use of bit derandomization techniques as specified in CCSDS 131.0-B-2 will ensure the proper bit synchronization process and interoperability between DSG and NASA/IP ground stations.

Comm-98: DSG shall use Non-Return-to-Zero-Level (NRZ-L) encoding for transmission of data streams to DSG-Ground on the High Rate RF link.

Rationale: NRZ-L is required to allow LDPC FEC codes to operate at maximum efficiency, producing the highest possible amount of coding gain. NRZ-L symbol L format encoding has better E_b/N_o performance than differential symbol format encoding like Non-Return-to-Zero-Mark (NRZ-M). Phase ambiguity resolution will be resolved by using a frame Attached Sync Marker (ASM) rather than using differential encoding like NRZ-M.

Comm-99: DSG-Ground shall use Non-Return-to-Zero-Level (NRZ-L) encoding for transmission of data streams to DSG on the High Rate RF link. (TBR-15)

Rationale: NRZ-L is required to allow LDPC FEC codes to operate at maximum efficiency, producing the highest possible amount of coding gain. NRZ-L symbol L format encoding has better E_b/N_o performance than differential symbol format encoding like Non-Return-to-Zero-Mark (NRZ-M). Phase ambiguity resolution will be resolved by using a frame Attached Sync Marker (ASM) rather than using differential encoding like NRZ-M.

Comm-100: DSG shall use the ASM for resolution of symbol phase ambiguity of received data streams from DSG-Ground on the High Rate RF link. (TBR-15)

Rationale: Phase ambiguity resolution will be resolved by using a frame ASM rather than using differential symbol format encoding like Non-Return-to-Zero-Mark (NRZ-M) since NRZ-L is needed to allow LDPC FEC codes to operate at maximum efficiency. NRZ-L also has better E_b/N_o performance than differential encoding like NRZ-M.

Comm-101: DSG-Ground shall use the ASM for resolution of symbol phase ambiguity of received data streams from DSG on the High Rate RF link.

Rationale: Phase ambiguity resolution will be resolved by using a frame ASM rather than using differential symbol format encoding like Non-Return-to-Zero-Mark (NRZ-M) since NRZ-L is needed to allow LDPC FEC codes to operate at maximum efficiency. NRZ-L also has better E_b/N_o performance than differential encoding like NRZ-M.

3.2.2.2.2.1.4 DATA LINK LAYER FRAMING HIGH RATE RF LINKS

Comm-102: DSG shall transmit data streams using data link framing as defined in CCSDS Advanced Orbiting Systems (AOS) Space Data Link Protocol, CCSDS 732.0-B-3, to DSG-Ground on the High Rate RF link.

Rationale: CCSDS 732.0-B-3 provides the structure for frame construction. Need to follow this standard to ensure interoperability between DSG and NASA/IP ground stations.

NOTE: CCSDS is working to baseline the Unified Space Link Protocol (USLP). Once the USLP blue book is baselined and all partners agree to implement it, this standard will be updated with the USLP blue book.

Comm-103: DSG-Ground shall receive data streams using data link framing as defined in CCSDS Advanced Orbiting Systems (AOS) Space Data Link Protocol, CCSDS 732.0-B-3, with DSG on the High Rate RF link.

Rationale: CCSDS 732.0-B-3 provides the structure for frame construction. Need to follow this standard to ensure interoperability between DSG and NASA/IP ground stations.

NOTE: CCSDS is working to baseline the Unified Space Link Protocol (USLP). Once the USLP blue book is baselined and all partners agree to implement it, this standard will be updated with the USLP blue book.

Comm-104: DSG-Ground shall transmit data streams using data link framing as defined in CCSDS Advanced Orbiting Systems (AOS) Space Data Link Protocol, CCSDS 732.0-B-3, to DSG on the High Rate RF link. (TBR-15)

Rationale: CCSDS 732.0-B-3 provides the structure for frame construction. Need to follow this standard to ensure interoperability between DSG and NASA/IP ground stations.

NOTE: CCSDS is working to baseline the Unified Space Link Protocol (USLP). Once the USLP blue book is baselined and all partners agree to implement it, this standard will be updated with the USLP blue book.

Comm-105: DSG shall receive data streams using data link framing as defined in CCSDS Advanced Orbiting Systems (AOS) Space Data Link Protocol, CCSDS 732.0-B-3, with DSG-Ground on the High Rate RF link. (TBR-15)

Rationale: CCSDS 732.0-B-3 provides the structure for frame construction. Need to follow this standard to ensure interoperability between DSG and NASA/IP ground stations.

NOTE: CCSDS is working to baseline the Unified Space Link Protocol (USLP). Once the USLP blue book is baselined and all partners agree to implement it, this standard will be updated with the USLP blue book.

3.2.2.2.2.1.5 NETWORK LAYER AND ABOVE FOR HIGH RATE RF LINKS

3.2.2.2.2.1.5.1 NETWORK LAYER

Comm-106: DSG shall transmit and receive (TBR-15) data streams using the CCSDS Encapsulation Service as defined in CCSDS 133.1-B-2 when communicating over CCSDS Data Link Layer Protocols with DSG-Ground on the High Rate RF link.

Rationale: CCSDS Data Link Layers are designed to carry either CCSDS Space Packets or Encapsulation Packets. The Encapsulation Service provides the compatibility between the higher layer data units and the CCSDS Data Link Layers.

Comm-107: DSG-Ground shall transmit (TBR-15) and receive data streams using the CCSDS Encapsulation Service as defined in CCSDS 133.1-B-2 when communicating over CCSDS Data Link Layer Protocols with DSG on the High Rate RF link.

Rationale: CCSDS Data Link Layers are designed to carry either CCSDS Space Packets or Encapsulation Packets. The Encapsulation Service provides the compatibility between the higher layer data units and the CCSDS Data Link Layers.

Comm-108: DSG shall transmit and receive (TBR-15) IP packets using the CCSDS IP over CCSDS standard CCSDS 702.1-B-1 when using IP packets over CCSDS Data Link Layers with DSG-Ground on the High Rate RF link.

Rationale: This allows IP packet use interoperability over CCSDS links.

Comm-109: DSG –Ground shall transmit (TBR-15) and receive IP packets using the CCSDS IP over CCSDS standard CCSDS 702.1-B-1 when using IP packets over CCSDS Data Link Layers with DSG on the High Rate RF link.

Rationale: This allows IP packet use interoperability over CCSDS links

Comm-110: DSG shall use IP as specified in IPv4 (RFC 791) or IPv6 (RFC 8200) (TBR-16) as a network layer with DSG-Ground on the High Rate RF link.

Rationale: IP provides for network layer services over interfaces that have low delay (under 5 sec (TBD)) and an expectation of real time end-to-end connectivity. Use of IP allows for maximum leverage of terrestrial networking developments under appropriate circumstances. IPv4-based technology is widely available in the commercial market. IPv6-only stack provides advantages such as increased security and more efficient routing. IPv6 technology is not as readily available.

Comm-111: DSG-Ground shall use IP as specified in IPv4 (RFC 791) or IPv6 (RFC 8200) (TBR-16) as a network layer with DSG on the High Rate RF link.

Rationale: IP provides for network layer services over interfaces that have low delay (under 5 sec (TBD)) and an expectation of real time end-to-end connectivity. Use of IP allows for maximum leverage of terrestrial networking developments under appropriate circumstances. IPv4-based technology is widely available in the commercial market. IPv6-only stack provides advantages such as increased security and more efficient routing. IPv6 technology is not as readily available.

3.2.2.2.2.1.5.2 TRANSPORT LAYER

Comm-112: DSG shall (TBR-7) implement Licklider Transmission Protocol (LTP) as specified in CCSDS Licklider Transmission Protocol for CCSDS, CCSDS 734.1-B-1 on the High Rate RF link.

Rationale: LTP is a reliable point-to-point transport protocol, over which the Bundle Protocols will run. LTP is not expected to be used for all links, but was designed for long-haul links with high delay.

Comm-113: DSG shall implement Transmission Control Protocol (TCP) as specified in RFC 793 on the High Rate RF link.

Rationale: TCP is a reliable transport protocol for use on IP networks.

Comm-114: DSG shall implement User Datagram Protocol (UDP) as specified in RFC 768 on the High Rate RF link.

Rationale: UDP provides best effort transport protocol for use on IP networks.

3.2.2.2.2.1.5.3 BUNDLE AND BUNDLE CONVERGENCE LAYER

Comm-115: DSG shall implement Delay Tolerant Networking Bundle Protocol as specified in CCSDS Bundle Protocol Specification, CCSDS 734.2-B-1 on the High Rate RF link.

Rationale: Provide lunar network and inter-planetary network functionality, e.g., network addressing, routing, and QoS management, in end-to-end communications environment of intermittent connectivity. When functioning as a relay, the DSG must have the capability to multiplex/demultiplex capability to deal with multiple data streams from multiple sources over heterogeneous links.

Comm-116: DSG should (TBR-18) implement the CCSDS standard "Streamlined Bundle Security Protocol" (DRAFT CCSDS 734.5-B-1) to secure DTN standard data bundles.

Rationale: Securing DTN bundles for transport is essential.

Comm-117: When DSG data links are not using secure DTN bundling, they should (TBR-19) provide for the option to implement Internet Protocol Security (IPSec) over IP links. IPSec is specified in RFC 6071.

Rationale: Application of IPSec to these data flows is strongly recommended to reduce mission risk when the data flows are not secured by the DTN Bundle security protocol.

Comm-118: DSG shall implement the Licklider Transmission Protocol Convergence Layer Adapter as specified in CCSDS 734.2-B-1 on the High Rate RF.

Rationale: In cases when Bundle Protocol is used over long delay or environments not conducive to IP-based convergence layers, LTP can provide reliable delivery. LTP may optionally be used over UDP [TBR]

Comm-119: DSG shall implement the Encapsulation Convergence Layer Adapter as specified in CCSDS 734.2-B-1 on the High Rate RF link.

Rationale: In circumstances when Bundle Protocol is used without a transport layer protocol, the encapsulation convergence layer adapter will allow bundles to be directly encapsulated and transmitted over CCSDS link layer protocols.

Comm-120: DSG should implement the TCP Convergence Layer Adapter as specified in RFC 7242 (TBR-17) on the High Rate RF link.

Rationale: When a hop between DTN nodes is carried over an IP network, the TCP convergence layer will provide reliable delivery of bundles. RFC 7242 is in the experimental stage and not a finalized standard.

Comm-121: DSG should implement the UDP Convergence Layer Adapter as specified in CCSDS 734.2-B-1 on the High Rate RF link.

Rationale: When a hop between DTN nodes is carried over an IP network, the UDP convergence layer will provide unreliable delivery of bundles. Addition of LTP over the UDP convergence layer may be used to provide reliable bundle delivery.

3.2.2.2.2.1.5.4 APPLICATION LAYER

Comm-122: All applications transferring data over this interface shall use either DTN Bundle Protocol or IP as specified above on the High Rate RF link.

Rationale: This will allow all data flows to be routable by intermediate nodes. Any application that expects to flow data to and from Earth either directly or relayed should use BP to accommodate delays or end-to-end link availability. Though IP may work in some Cislunar cases, use of BP will allow the application to also function in deep space cases.

Comm-123: DSG shall use CCSDS File Delivery Protocol Class 1 and Class 2 as defined in *CCSDS File Delivery Protocol (CFDP),* CSDS 727.0-B-4 transmit and receive application layer files on the High Rate RF link.

Rationale: Provide reliable, accountable transfer of files.

Comm-124: DSG should (TBR-14) use asynchronous message service (AMS) as defined in Asynchronous Message Service (AMS) CCSDS 735.1-B-1 to transmit and receive messages on the High Rate RF link.

Rationale: provides a standard, reusable infrastructure for the exchange of information among data system modules in a manner that is simple to use, highly automated, flexible, robust, scalable, and efficient.

3.2.2.2.2.1.6 SECURITY ON HIGH RATE RF LINKS

The following define the security standards to ensure interoperability for the High Rate RF DSG to DSG-Ground links. The actual links & data to be protected, security & key management, etc. will be based on the International Partner agreement on security policies for the Program(s).

Comm-125: DSG shall implement CCSDS Cryptographic Algorithms, *CCSDS 352.0-B-1*, Advanced Encryption Standard (AES), for encryption and decryption (TBR-15) of data exchanges with DSG-Ground on the High Rate RF link.

Rationale: AES is the algorithm of choice for Federal Information Systems per FIPS PUB 197.

Comm-126: DSG-Ground shall implement CCSDS Cryptographic Algorithms, *CCSDS 352.0-B-1*, Advanced Encryption Standard (AES), for encryption (TBR-15) and decryption of data exchanges with DSG on the High Rate RF link.

Rationale: AES is the algorithm of choice for Federal Information Systems per FIPS PUB 197.

Comm-127: DSG shall implement the Advanced Encryption Standard specifically the Galois Counter Mode (AES-GCM) algorithm per NIST SP 800-38D, with 256-bit keys, 96-bit Initialization Vectors (IVs), and with authentication tag lengths of 128 bits truncated to 64 bits for data exchanges with DSG-Ground on the High Rate RF link. *Programs need to assess the level of Security Information Assurance and Risks for non-command and control links, and shall select an appropriate AES mode commensurate with those risks, and implement MOU/MOA agreements to handle applicable circumstances*.

Rationale: The use of AES-GCM is an efficient implementation for encryption and authentication of data and information exchanges.

Comm-128: DSG-Ground shall implement the Advanced Encryption Standard specifically the Galois Counter Mode (AES-GCM) algorithm per NIST SP 800-38D, with 256-bit keys, 96-bit Initialization Vectors (IVs), and with authentication tag lengths of 128 bits truncated to 64 bits for data exchanges with DSG on the High Rate RF link. *Programs need to assess the level of Security Information Assurance and Risks for non-command and control links, and shall select an appropriate AES mode commensurate with those risks, and implement MOU/MOA agreements to handle applicable circumstances*.

Rationale: The use of AES-GCM is an efficient implementation for encryption and authentication of data and information exchanges.

Comm-129: DSG shall implement link layer security as specified by CCSDS 355.0-B-1, Space Data Link Security Protocol for data exchanges with DSG-Ground on the High Rate RF link.

Rationale: Use CCSDS standards to ensure interoperability and compatibility.

Comm-130: DSG-Ground shall implement link layer security as specified by CCSDS 355.0-B-1, Space Data Link Security Protocol for data exchanges with DSG on the High Rate RF link.

Rationale: Use CCSDS standards to ensure interoperability and compatibility.

Comm-131: DSG shall implement authentication as specified by *CCSDS 355.0-B-1* CCSDS Cryptographic Algorithms for data exchanges with DSG-Ground on the High Rate RF link.

Rationale: DSG needs to support authentication in addition to encryption.

Comm-132: DSG-Ground shall implement authentication as specified by *CCSDS 355.0-B-1* CCSDS Cryptographic Algorithms for data exchanges with DSG on the High Rate RF link.

Rationale: DSG needs to support authentication in addition to encryption.

Comm-133: DSG shall be able to enable or disable encryption to support contingency operations with DSG-Ground on the High Rate RF link.

Rationale: DSG needs to be able to turn off encryption to support spacecraft recovery, contingency modes, etc.

Comm-134: DSG-Ground shall be able to enable or disable encryption to support contingency operations with DSG on the High Rate RF link.

Rationale: DSG-Ground needs to be able to turn off encryption to support spacecraft recovery, contingency modes, etc

Comm-135: DSG shall employ key management techniques as defined in TBD-1 with DSG-Ground on the High Rate RF link. (TBD-1 could be SDLS Extended Procedures standard (Draft CCSDS 355.1-B-1) as noted below)

Rationale: This requirement ensures that keys are managed in an interoperable manner.

Note: CCSDS is working on the SDLS Extended Procedures standard (CCSDS 355.1-B-1)*. Once the standard is baselined and all partners agree to implement it, this standard will be updated with the Symmetric Key Management blue book.*

Comm-136: DSG-Ground shall employ key management techniques as defined in TBD-1 with DSG on the High Rate RF link. (TBD-1 could be SDLS Extended Procedures standard (Draft CCSDS 355.1-B-1) as noted below)

Rationale: This requirement ensures that keys are managed in an interoperable manner.

> *Note: CCSDS is working on the* SDLS Extended Procedures standard (CCSDS 355.1-B-1)*. Once the standard is baselined and all partners agree to implement it, this standard will be updated with the Symmetric Key Management blue book.*

3.2.2.2.2.2 OPTICAL LINKS

Optical links between DSG and Earth can be used to validate performance and extensibility to deep space or to augment/provide higher rate links. High-Photon Efficiency Optical standards (for Deep Space Optical links) have been agreed to at the CCSDS level and the working group is drafting a CCSDS Blue book to capture the standard. The Blue Book will define downlink and uplink optical waveforms for communications at interplanetary distances. For DSG operations in cis-Lunar space, the Blue Book downlink specification may be used to provide high rate communications for both forward and return links, as is being done for the Orion EM-2 Optical Communications system.

For DSG to the lunar surface and for other proximity links, it may be possible in the future to use either a High Data Rate Optical (HDRO) Communications standard or an Orbital On-Off Keying (O3K) standard. The HDRO standard would offer higher data rates for shorter distances compared to the High Photon Efficiency system already envisioned. The CCSDS plans to develop a HDRO standard (Blue Book); in the meantime two Orange Books (experimental) are in development. One Orange Book is focused on 1550 nm systems while the other is focused on 1064 nm. Alternatively, an O3K standard would be consistent with emerging commercial capabilities offering lower performance at lower cost. The CCSDS plans to develop an O3K Blue Book.

TBD-5 – standards for Optical Communication.

3.2.2.2.3 CONTINGENCY COMMUNICATION LINKS

(Future Work) TBD-8

The IOAG is currently working on defining the standards for contingency/emergency communications as well as the process for declaring a spacecraft emergency. Once their recommendations has been finalized and agreed to by all participating international partners, they will be included in this section. A summary of draft standards consistent with what is currently being considered by the IOAG is given in Table 3.2.2.2-4.

TABLE 3.2.2.2-4 DRAFT STANDARDS FOR CONTINGENCY COMMUNICATION LINK

	Frequency Bands[1]	Modulation[2]	Coding[3]	Space Data Link Protocol	Space Data Link Security	Ranging
Earth to DSG Emergency/contingency ≤ 4 Ksps	7190-7235 MHz	PCM/PSK/PM - Modulation on subcarrier	Option 1 – BCH Option 2 - LDPC[3]: • Coding rates: - 1/2, • Codeblock size: - 128 octets for LDPC rate 1/2,	AOS[4], USLP[5] • AOS frame size: - 128 octets and 64 bit ASM for	CCSDS Space Data Link Security Protocol[8]	CCSDS PN[7] • Non-regenerative. • Ranging chip rate: ≤ 2 Mcps.

				LDPC rate $^1/_2$),		
DSG to Earth Nominal: ≤ 20 Ksps	8450-8500 MHz	PCM/PSK/PM - Modulation on subcarrier	Option 1 – concatenated RS, convolutional[3] Option 2 - LDPC[3, 6]: • Coding rates: - $^1/_2$, • Codeblock size: 128 octets for LDPC rate $^1/_2$	AOS[4], USLP[5] - AOS frame size: - 128 octets and 64 bit ASM for LDPC rate $^1/_2$),)	CCSDS Space Data Link Security Protocol[8]	CCSDS PN[7] • Non-regenerative. • Ranging chip rate: ≤ 2 Mcps.

17. SFCG 32-2R1 Communication Frequency Allocations and Sharing in the Lunar Region.
18. CCSDS 401.0-B-27 Radio Frequency and Modulation Systems--Part 1: Earth Stations and Spacecraft. Blue Book.
19. CCSDS 131.0-B-3 TM Synchronization and Channel Coding. Blue Book.
20. CCSDS 732.0-B-3 AOS Space Data Link Protocol. Blue Book.
21. CCSDS 732.1-R-3.1 Unified Space Data Link Protocol. Red Book. November 2017, currently undergoing publication.
22. CCSDS (TBD Reference) Coding & Synchronization Sub-layer High Rate Uplink Protocol for AOS & USLP.
23. CCSDS 414.1-B-2 Pseudo-Noise (PN) Ranging Systems. Blue Book.
24. CCSDS 355.0-B-1 Space Data Link Security Protocol. Blue Book.

3.2.2.3 DSG – VISITING VEHICLE COMMUNICATION LINKS

DSG to Visiting Vehicle (VV) link is the space to space link between DSG and a visiting vehicles like Orion. The VV will rendezvous and dock/berth to the DSG. The DSG to VV link will be used to exchange information as well as for radiometric tracking. This link is compatible with the Orion Space to Space Link at S-band and needs to meet the Orion space-to-space link standards and requirements. The detailed breakdown of data transferred between DSG and a visiting vehicle is given in Appendix D

Orion's S-band system is designed to support space-to-space ranging to provide radiometric measurements. The system, in Point B mode, generates, modulates and transmits the range channel data; and it receives and processes the coherent turn-around ranging channel and carrier to obtain the range and range-rate measurements. The system, in Point A mode, coherently retransmits the received carrier and range channel to support radiometric measurements. The Orion system can support both Point A and Point B mode. For this application, the S-band system on the Orion/Visiting vehicle side is in Point B mode and the DSG is in Point A mode. Orion/Visiting vehicle generates, modulates and transmits the ranging channel, the DSG receives and coherently turns it around. Orion again receives, demodulates and processes the range channel and carrier to make the range and range rate measurements. The section below describe the standards and protocols for the DSG – VV links.

3.2.2.3.1 FREQUENCY

Comm-137: DSG shall use 2200-2290 MHz (S-band) frequency band to transmit signals to the VV.

Rational: Use of near-Earth S-band is compliant with ITU and CCSDS/SFCG recommendations. S-band is used to communicate with

Visiting Vehicle (Orion) to be compatible with Orion S-band system. The S-band frequency pairs used for this link will be captured in the DSG – Orion/VV Interface Requirements Documents (IRDs).

Comm-138: VV shall use 2200-2290 MHz (S-band) frequency band to receive signals from the DSG.

Rational: Use of near-Earth S-band is compliant with ITU and CCSDS/SFCG recommendations. S-band is used to communicate with Visiting Vehicle (Orion) to be compatible with Orion S-band system. The S-band frequency pairs used for this link will be captured in the DSG – Orion/VV Interface Requirements Documents (IRDs).

Comm-139: DSG shall use 2025-2110 MHz (S-band) frequency band to receive signals from VV.

Rational: Use of near-Earth S-band is compliant with ITU and CCSDS/SFCG recommendations. S-band is used to communicate with Visiting Vehicle (Orion) to be compatible with Orion S-band system.

Comm-140: VV shall use 2025-2110 MHz (S-band) frequency band to transmit signals to DSG.

Rational: Use of near-Earth S-band is compliant with ITU and CCSDS/SFCG recommendations. S-band is used to communicate with Visiting Vehicle (Orion) to be compatible with Orion S-band system.

3.2.2.3.2 MODULATION AND SIGNAL CHARACTERISTICS

Comm-141: VV shall generate and transmit the carrier, short and long PN codes to the DSG.

Rational: The VV will act like the Space Network ground terminal as described in 450-SNUG, Space Network Users Guide (SNUG).

Comm-142: DSG shall coherently retransmit the received carrier with a turn-around ratio of 240/221(transmit/receive) for coherent DSG – VV operations.

Rational: The 240/221 turn-around ratio is required to be compatible with Orion and is described in the 450-SNUG, Space Network Users Guide (SNUG). Coherent link operation is required for providing the radiometric measurements of range and range rate.

Comm-143: DSG shall coherently retransmit the received range channel data to the VV.

Rationale: In order to provide range data at the VV, the received range channel data at the DSG (Point A System) must be coherently retransmitted to VV (Point B Systems).

Comm-144: DSG shall provide a non-coherent mode of operation on DSG – VV links.

Rationale: Non-coherent operation is required in order that DSG can deliver telemetry and permit tracking to be performed when it does not receive a signal from Earth. When two-way radiometric measurements are not required, a non-coherent mode of operation may be preferred since signal acquisition and tracking is easier, faster, and requires a lower Eb/No.

Comm-145: DSG shall automatically switch to a non-coherent mode of operation on DSG – VV links if it loses the signal from the VV.

Rationale: Without automatic switching to non-coherent mode, loss of the signal from VV could cause the DSG to stop transmitting as well. A good option is to "freeze" the current carrier frequency and PN chip rate when the link from the VV is lost, and maintain the same modulation on DSG transmission to the VV.

Comm-146: VV shall process the received carrier to make radiometric measurements of one-way or two-way range rate data for the DSG – VV links.

Rationale: The VV (Point B) vehicle should measure one-way range rate (non-coherent DSG) or two-way range rate (coherent DSG) to support rendezvous maneuvering with the DSG.

Comm-147: VV shall process the coherent turned-around ranging channel data to provide radiometric measurements of range data for the DSG – VV links.

Rationale: The VV (Point B) vehicle should measure range to DSG to support rendezvous maneuvering with the DSG.

Comm-148: VV shall receive signals with modulation schemes in accordance with Table 3.2.2.3-1 Point A Signal Characteristics for DSG-VV links.

Rationale: Proximity modulation schemes are chosen to be compatible with Orion and existing ground infrastructure as described in 450-SNUG, Section 6.3 for the SN. The SN Data Group 1 (DG1)/mode 3 and DG2 modulations are supported by both the Point A and Point B side of a link for rendezvous radiometrics simultaneous with higher data rates.

Comm-149: DSG shall transmit signals with modulation schemes in accordance with Table 3.2.2.3-1 Point A Signal Characteristics for DSG-VV links.

Rationale: Proximity modulation schemes are chosen to be compatible with Orion and existing ground infrastructure as described in 450-SNUG, Section 6.3 for the SN. The SN Data Group 1 (DG1)/mode 3 and DG2 modulations are supported by both the Point A and Point B side of a link for rendezvous radiometrics simultaneous with higher data rates.

Comm-150: DSG shall transmit one data stream using alternate symbols on the inphase (I) and quadrature (Q) modulation channels when using Data Group 1 (DG1) mode 1, DG1 mode 2, or DG2.

Rationale: DG1 can accept either one data stream (split between the I and Q channels) or two independent data streams. One data stream is chosen to be compatible with Orion.

Comm-151: VV shall receive one data stream using alternate symbols on the inphase (I) and quadrature (Q) modulation channels when using Data Group 1 (DG1) mode 1, DG1 mode 2, or DG2.

Rationale: DG1 can accept either one data stream (split between the I and Q channels) or two independent data streams. One data stream is chosen to be compatible with Orion.

Comm-152: DSG shall transmit one data stream on the quadrature (Q) modulation channel and a Pseudo Noise (PN) ranging code on the inphase (I) modulation channel when using Data Group 1 (DG1) mode 3.

Rationale: DG1 mode 3 is used when both PN code ranging and a higher data rate than can be accommodated by DG1 mode 1 or 2 is desired. DG1 mode 3 accepts a high data rate stream on the Q channel. DG1 mode 3 can accept either a LDR stream on the I channel with the ranging code or no data on the I channel with the ranging code. One data stream on the Q channel is used to be compatible with Orion.

Comm-153: VV shall receive one data stream on the quadrature (Q) modulation channel and a Pseudo Noise (PN) ranging code on the inphase (I) modulation channel when using Data Group 1 (DG1) mode 3.

Rationale: DG1 mode 3 is used when both PN code ranging and a higher data rate than can be accommodated by DG1 mode 1 or 2 is desired. DG1 mode 3 accepts a high data rate stream on the Q channel. DG1 mode 3 can accept either a LDR stream on the I channel with the ranging code or no data on the I channel with the ranging code. One data stream on the Q channel is used to be compatible with Orion.

TABLE 3.2.2.3-1 POINT A SIGNAL CHARACTERISTICS FOR DSG-VISTING VEHICLE LINKS

Link Type Coded	Symbol Rate	Data Group	Mode	Doppler Measurement	PN Ranging	Modulation	PN Spreading
DG1 coherent mode 1	>= 18 Ksps <= 600 Ksps	DG1 Coherent	Mode 1	Two-Way	Yes	Balanced SQPN	Yes
DG1 non-coherent mode 2	>= 18 Ksps <= 600 Ksps	DG1 Non-Coherent	Mode 2	One-Way	No	Balanced SQPN	Yes
DG1 coherent mode 3	>= 18 Ksps <= 6 Msps	DG1 Coherent	Mode 3	Two-Way	Yes	Spread Spectrum (I Only) Unbalanced QPSK [1]	Yes

DG2 coherent	>= 600 Ksps <= 6 Mbps	DG2 Coherent	-	Two-Way	No	Balanced SQPSK	No
DG2 non-coherent	>= 300 Ksps <= 6 Msps	DG2 Non-Coherent	-	One-Way	No	Balanced SQPSK	No
DG2 non-coherent	>= 6 Msps <= 20 Msps	DG2 Non-Coherent	-	One-Way	No	Balanced SQPSK	No
NOTE: (1) Power ratio is (1:4), I-channel is PN-only, and Q-channel is data-only							

Comm-154: VV shall transmit signals to DSG using SS-UQPSK modulation as shown in Table 3.2.2.3-2 Point B Signal Characteristics.

Rationale: Proximity modulation schemes are chosen to be compatible with Orion and existing ground infrastructure as described in 450-SNUG, Section 6.2 for the SN. The SS-UQPSK modulation is supported by both the Point A and Point B side of a link for rendezvous radiometrics simultaneous with low data rates.

Comm-155: DSG shall receive signals from VV with SS-UQPSK modulation schemes in accordance with Table 3.2.2.3-2 Point B Signal Characteristics.

Rationale: Modulation schemes are chosen to be compatible with Orion and existing ground infrastructure as described in 450-SNUG, Section 6.3 for the SN. The SS-UQPSK modulation is supported by both the Point A and Point B side of a link for rendezvous radiometrics simultaneous with low data rates.

TABLE 3.2.2.3-2 POINT B SIGNAL CHARACTERISTICS FOR DSG-VISTING VEHICLE LINKS

Link Type	Coded Symbol Rate	PN Ranging	Modulation	PN Spreading
SQPN 1	>= 18 Ksps <= 300 Ksps	Yes	Spread Spectrum Unbalanced QPSK (10:1)	Yes

3.2.2.3.3 ANTENNA POLARIZATION

Comm-156: DSG shall transmit using right hand circular polarization on DSG to VV links.

Rationale: RHCP is selected because to be compatible with Orion.

Comm-157: DSG shall receive using right hand circular polarization on VV to DSG links.

Rationale: RHCP is selected because to be compatible with Orion.

Comm-158: VV shall transmit using right hand circular polarization on DSG to VV links.

Rationale: RHCP is selected because to be compatible with Orion.

Comm-159: VV shall receive using right hand circular polarization on DSG to VV links.

Rationale: RHCP is selected because to be compatible with Orion.

3.2.2.3.4 CODING AND SYNCHRONIZATION

Comm-160: DSG and VV shall use CCSDS Rate 1/2 k=1024 Low Density Parity Code as defined in Section 7, TM Synchronization and Channel Coding, CCSDS 131.0-B-3, for encoding data on DSG – VV links.

Rationale: Coding gain provided by LDPC codes is ~2dB more than that provided by concatenated Reed-Solomon/convolutional codes. Using rate ½ LDPC code to be compatible with Orion.

Comm-161: DSG and VV shall use CCSDS Rate ½ k=1024 Low Density Parity Code as defined in Section 7, TM Synchronization and Channel Coding. CCSDS 131.0-B-3, for decoding data on DSG – VV links

Rationale: Coding gain provided by LDPC codes is ~2dB more than that provided by concatenated Reed-Solomon/convolutional codes. Using rate ½ LDPC code to be compatible with Orion.

Comm-162: DSG and VV shall enable and disable communication link forward error correction (FEC) on DSG- VV links upon receipt of command.

Rationale: DSG needs to able to enable or disable FEC to support contingency and other operational scenarios.

Comm-163: DSG and VV shall apply the 64-bit Attached Sync Marker (ASM) defined in Section 8, *TM Synchronization and Channel Coding,* CCSDS 131.0-B-3 to transmitted frames on the DSG – VV links.

Rationale: Use of the 64-bit CCSDS frame sync pattern identified as ASM for Rate ½LDPC Coded Data provides the receiver the ability to synchronize at the start of a FEC code block frame and will ensure interoperability between DSG and Orion/VV. Using the same 64 bit ASM for non-FEC coded block frames will maintain a common frame structure for all coded and uncoded frames.

Comm-164: DSG and VV shall use the 64-bit Attached Sync Marker (ASM) defined in Section 8, *TM Synchronization and Channel Coding,* CCSDS 131.0-B-3 for synchronization of received frames on the DSG-VV links.

Rationale: Use of the 64-bit CCSDS frame sync pattern identified as ASM for Rate ½, 2/3, and 4/5 LDPC Coded Data provides the receiver the ability to synchronize at the start of a FEC code block frame and will ensure interoperability between DSG and Orion/VV. Using the same 64 bit ASM for non-FEC coded block frames will maintain a common frame structure for all coded and uncoded frames.

Comm-165: DSG and VV shall use bit randomization techniques in accordance with CCSDS 131.0-B-3 for randomization of transmitted data streams on DSG-VV links.

Rationale: Use of bit randomization techniques as specified in CCSDS 131.0-B-2 will ensure the proper bit synchronization process and interoperability between DSG and Orion/VV

Comm-166: DSG and VV shall use bit derandomization techniques in accordance with CCSDS 131.0-B-3 for derandomization of received data streams on DSG-VV links.

Rationale: Use of bit derandomization techniques as specified in CCSDS 131.0-B-2 will ensure the proper bit synchronization process and interoperability between DSG and Orion.

Comm-167: DSG and VV shall use Non-Return-to-Zero-Level (NRZ-L) encoding for transmission of data streams on DSG-VV links.

Rationale: NRZ-L is required to allow LDPC FEC codes to operate at maximum efficiency, producing the highest possible amount of coding gain. NRZ-L symbol L format encoding has better Eb/No performance than differential symbol format encoding like Non-Return-to-Zero-Mark (NRZ-M). Phase ambiguity resolution will be resolved by using a frame Attached Sync Marker (ASM) rather than using differential encoding like NRZ-M.

Comm-168: DSG and VV shall use the ASM for resolution of symbol phase ambiguity of received data streams.

Rationale: Phase ambiguity resolution will be resolved by using a frame ASM rather than using differential symbol format encoding like Non-Return-to-Zero-Mark (NRZ-M) since NRZ-L is needed to allow LDPC FEC codes to operate at maximum efficiency. NRZ-L also has better Eb/No performance than differential encoding like NRZ-M.

3.2.2.3.5 DATA LINK LAYER FRAMING

Comm-169: DSG and VV shall transmit data streams using data link framing as defined in CCSDS Advanced Orbiting Systems (AOS) Space Data Link Protocol, CCSDS 732.0-B-3 September, 2015 on DSG-VV links.

Rationale: CCSDS 732.0-B-3 provides the structure for frame construction. Need to follow this standard to ensure interoperability between DSG and Orion.

Comm-170: DSG and VV shall receive data streams using data link framing as defined in CCSDS Advanced Orbiting Systems (AOS) Space Data Link Protocol, CCSDS 732.0-B-3 September, 2015 on DSG-VV links.

Rationale: CCSDS 732.0-B-3 provides the structure for frame construction. Need to follow this standard to ensure interoperability between DSG and Orion.

Comm-171: DSG and VV shall use the Channel Access Data Unit (CADU) shown in Table 3.2.2.3-3 when transmitting or receiving FEC coded or uncoded data streams on DSG-VV links.

Rationale: Required for compatibility with Orion.

The protocol stack for coded DSG-VV link is provided in Figure 3.2.2.3-1 and the protocol stack for the uncoded DSG-VV link is provided in Figure 3.2.2.3-2 to provide a visualization of how the data is formatted into the frames

TABLE 3.2.2.3-3 - CHANNEL ACCESS DATA UNIT (CADU) CHARACTERISTICS (CODED AND UNCODED)

Coding	Security Mode	ASM	Transfer Frame Header	Transfer Frame Data				Frame Error Control	LDPC Code Parity Field	AOS-VCP Transfer Frame Length	AOS Code Block Frame Length	CADU Length
Rate ½ LDPC Coded	All	64 bits	48 bits	976 bits				N/A	1024 bits	1024 bits	2048 bits	2112 bits
				Security Header	M_PDU Header	M_PDU Packet Zone	Security Trailer					
	Encryption Only			64 bits	16 bits	896 bits	N/A					
	Encryption + Authentication			64 bits	16 bits	832 bits	64 bits					
	Security Bypass			N/A	16 bits	960 bits	N/A					
Uncoded	All	64 bits	48 bits	1984 bits				16 bits	N/A	2048 bits	2048 bits	2112 bits
				Security Header	M_PDU Header	M_PDU Packet Zone	Security Trailer					
	Encryption Only			64 bits	16 bits	1904 bits	N/A					
	Encryption + Authentication			64 bits	16 bits	1840 bits	64 bits					
	Security Bypass			N/A	16 bits	1968 bits	N/A					

Notes:

M_PDU or Encrypted M_PDU = M_PDU Header + M_PDU Packet Zone
AOS-VCP Transfer Frame = Transfer Frame Header + Transfer Frame Data + Frame Error Control (if applicable)
AOS Code Block Frame = AOS-VCP Transfer Frame + LDPC Code Parity Field
CADU Length = ASM + AOS Code Block Frame

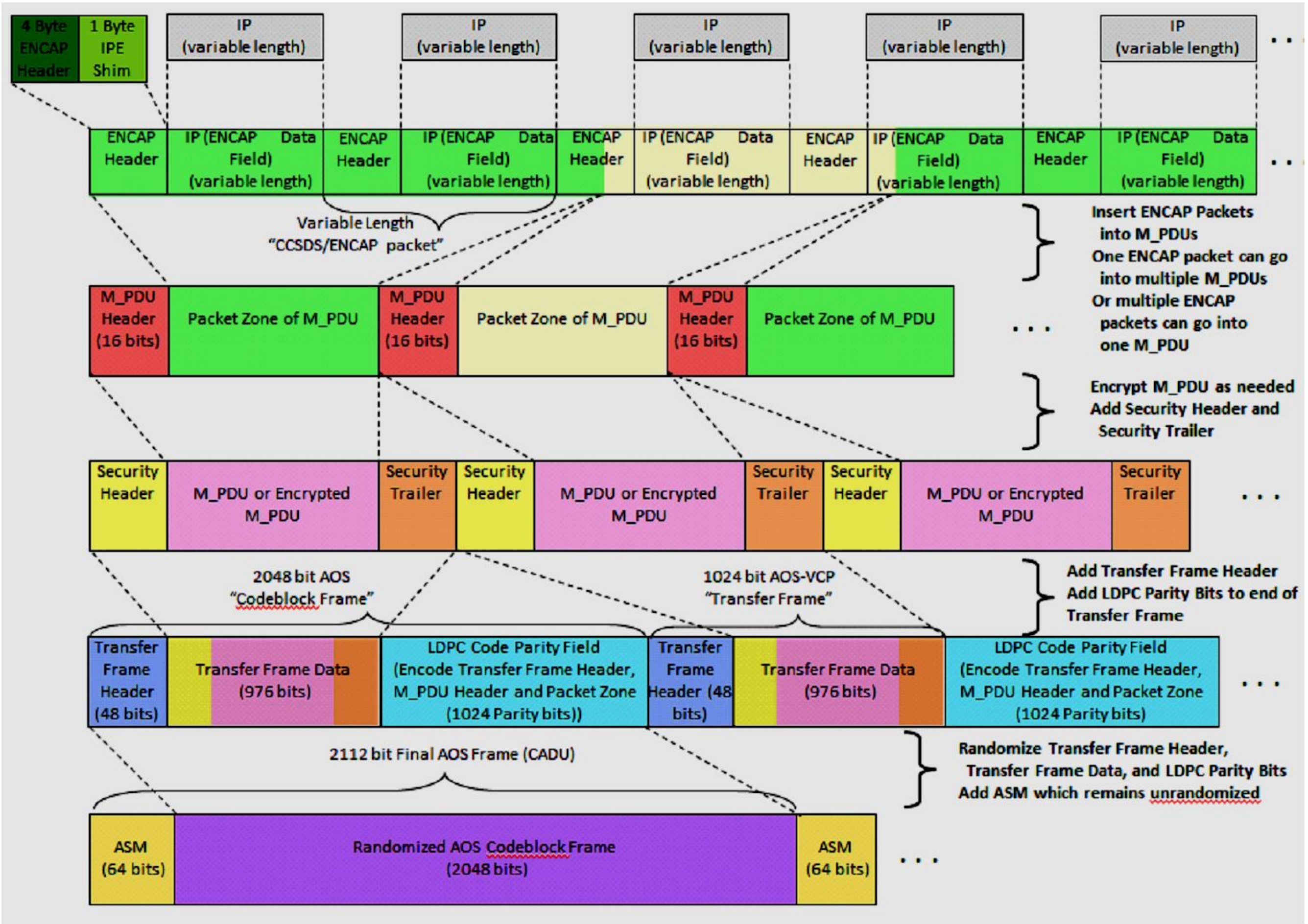


FIGURE 3.2.2.3-1 - PROTOCOL STACK FOR RATE ½ LDPC CODED LINKS

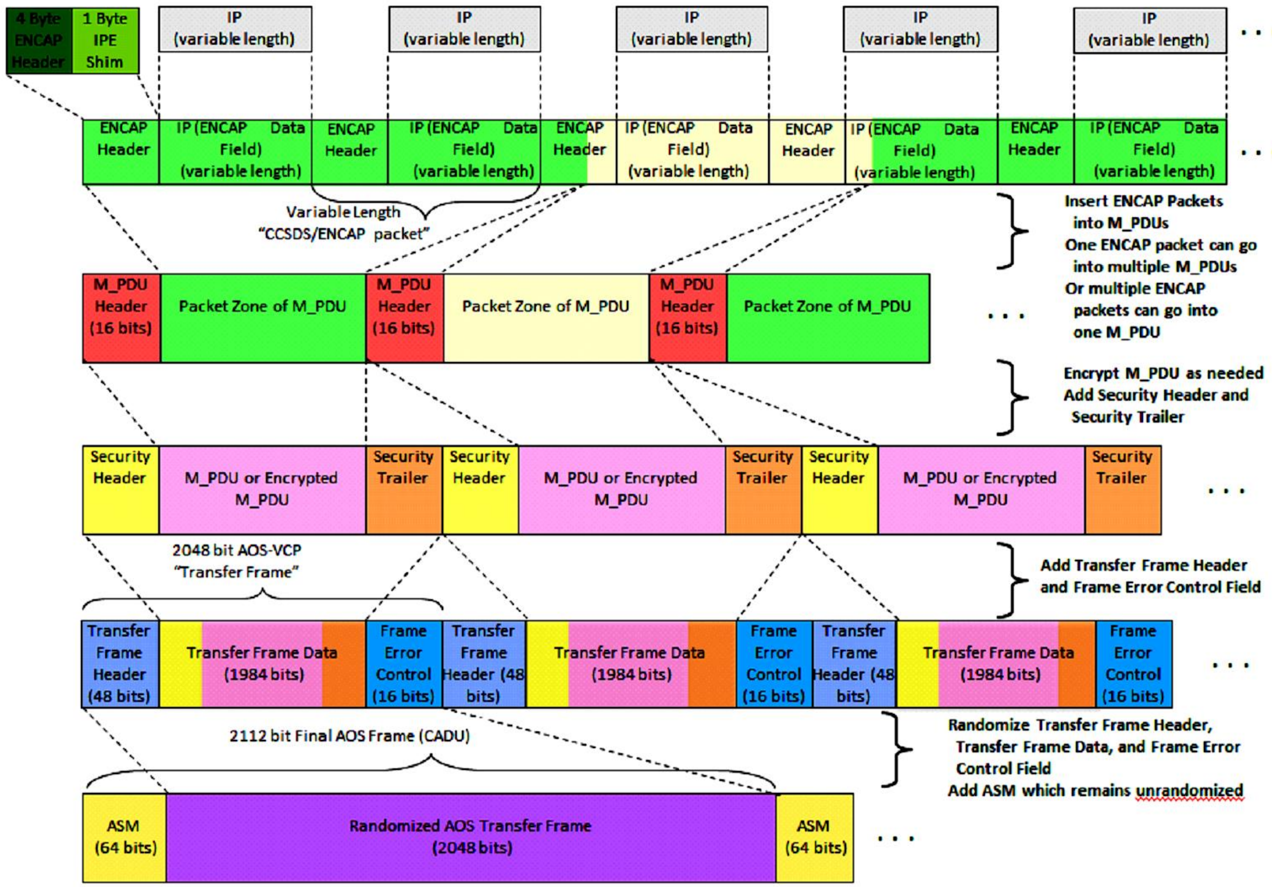


FIGURE 3.2.2.3-2 - PROTOCOL STACK OPTION FOR UNCODED LINKS

3.2.2.3.6 NETWORK AND FILE/MESSAGE LAYERS

Comm-172: DSG and VV shall use CCSDS File Delivery Protocol as defined in *CCSDS File Delivery Protocol (CFDP),* CCSDS 727.0-B-4 January 2007 on DSG-VV links.

Rationale: Provide reliable, accountable transfer of application data between the end nodes or between 2 nodes over point-to-point space link.

Comm-173: DSG and VV shall encapsulate IP packets using the CCSDS Encapsulation Service (CCSDS 133.1-B-2, Encapsulation Service, and CCSDS 702.1-B-1, IP Over CCSDS Space Links) on DSG-VV links.

Rationale: The CCSDS standard for transferring IP packets over a space link is to prepend CCSDS Internet Protocol Extension (IPE) octet(s) to each IP packet and encapsulate the result in a CCSDS Encapsulation packet as described in CCSDS 702.1-B-1 and CCSDS 133.1-B.2. The Space Assigned Number Authority (SANA) registry lists the CCSDS recommended protocols to be encapsulated and their enumerations for the content of the IPE header.

Comm-174: DSG shall implement Delay Tolerant Networking Bundle Protocol as specified in CCSDS Bundle Protocol Specification, CCSDS 734.2-B-1 on the DSG-VV link.

Rationale: Provide lunar network and inter-planetary network functionality, e.g., network addressing, routing, and QoS management, in end-to-end communications environment of intermittent connectivity. When functioning as a relay, the DSG must have the capability to multiplex/demultiplex capability to deal with multiple data streams from multiple sources over heterogeneous links.

Comm-175: VV shall (TBR-20) implement Delay Tolerant Networking Bundle Protocol as specified in CCSDS Bundle Protocol Specification, CCSDS 734.2-B-1 on the DSG-VV link.

Rationale: Provide lunar network and inter-planetary network functionality, e.g., network addressing, routing, and QoS management, in end-to-end communications environment of intermittent connectivity. When functioning as a relay, the DSG must have the capability to multiplex/demultiplex capability to deal with multiple data streams from multiple sources over heterogeneous links

Comm-176: DSG and VV should (TBR-18) implement the CCSDS standard "Streamlined Bundle Security Protocol" (DRAFT CCSDS 734.5-B-1) to secure DTN standard data bundles on the DSG-VV link.

Rationale: Securing DTN bundles for transport is essential.

Comm-177: When DSG – VV data links are not using secure DTN bundling, they should (TBR-19) provide for the option to implement Internet Protocol Security (IPSec) over IP links. IPSec is specified in RFC 6071.

Rationale: Application of IPSec to these data flows is strongly recommended to reduce mission risk when the data flows are not secured by the DTN Bundle security protocol.

Comm-178: DSG shall implement the Licklider Transmission Protocol Convergence Layer Adapter as specified in CCSDS 734.2-B-1 on the DSG-VV link.

Rationale: In cases when Bundle Protocol is used over long delay or environments not conducive to IP-based convergence layers, LTP can provide reliable delivery. LTP may optionally be used over UDP [TBR]

Comm-179: VV shall (TBR-21) implement the Licklider Transmission Protocol Convergence Layer Adapter as specified in CCSDS 734.2-B-1 on the DSG-VV link.

Rationale: In cases when Bundle Protocol is used over long delay or environments not conducive to IP-based convergence layers, LTP can provide reliable delivery. LTP may optionally be used over UDP [TBR]

Comm-180: DSG shall implement the Encapsulation Convergence Layer Adapter as specified in CCSDS 734.2-B-1 on the DSG-VV link.

Rationale: In circumstances when Bundle Protocol is used without a transport layer protocol, the encapsulation convergence layer adapter will allow bundles to be directly encapsulated and transmitted over CCSDS link layer protocols.

Comm-181: VV shall (TBR-20) implement the Encapsulation Convergence Layer Adapter as specified in CCSDS 734.2-B-1 on the DSG-VV link.

Rationale: In circumstances when Bundle Protocol is used without a transport layer protocol, the encapsulation convergence layer adapter will allow bundles to be directly encapsulated and transmitted over CCSDS link layer protocols.

Comm-182: DSG and VV should implement the TCP Convergence Layer Adapter as specified in RFC 7242 (TBR-17) on the DSG-VV link.

Rationale: When a hop between DTN nodes is carried over an IP network, the TCP convergence layer will provide reliable delivery of bundles. RFC 7242 is in the experimental stage and not a finalized standard.

Comm-183: DSG and VV should implement the UDP Convergence Layer Adapter as specified in CCSDS 734.2-B-1 on the on the DSG-VV link.

Rationale: When a hop between DTN nodes is carried over an IP network, the UDP convergence layer will provide unreliable delivery of bundles.

Addition of LTP over the UDP convergence layer may be used to provide reliable bundle delivery.

3.2.2.3.7 SECURITY

Comm-184: DSG and VV shall implement FIPS PUB 197, Advanced Encryption Standard (AES), for all encryption of inter-system data exchanges on DSG-VV links.

Rationale: AES has replaced the Digital Encryption Standard (DES) as the algorithm of choice for Federal Information Systems per FIPS PUB 197. Compatibility with Orion.

Comm-185: DSG and VV shall implement the Advanced Encryption Standard - Galois Counter Mode (AES-GCM) algorithm per NIST SP 800-38D, with 256-bit keys, 96-bit Initialization Vectors (IVs), and with authentication tag lengths of 128 bits truncated to 64 bits on DSG-VV links.

Rationale: The use of AES-GCM is an efficient implementation for encryption and authentication of data and information exchanges. Compatibility with Orion.

Comm-186: DSG and VV shall implement link layer security as specified by CCSDS 355.0-R-4, Space Data Link Security Protocol on DSG-VV links.

Rationale: Compatibility with Orion

3.2.2.4 PROXIMITY COMMUNICATIONS: DSG – EVA COMMUNICATIONS LINK

There will be DSG based EVA for contingencies and/or emergencies. The current DSG habitation system is being designed to accommodate a maximum of 4 EVA crew members. During EVAs, there will be 2 EVA crew members outside the DSG at any given time. There will be no EVAs during any rendezvous, docking, berthing, etc. operations. The DSG will relay the EVA data to/from Earth. When there are crewed lunar surface operations, the EVAs will be based off of lunar rovers and/or lunar habitat. There will be up to 4 EVA crew members on the lunar surface and they communicate with the rover/habitat. The rover/habitat will relay EVA data to/from Earth and/or DSG.

EVAs have a requirement for high-reliability, robust, low rate communications for audio, biomedical and suit telemetry (critical data) with ranges up to 500 meters between each other and/or between the EVA and the DSG. EVAs have a need for high rate data transfer for imagery, etc. with communication ranges up to 300 meters. The EVAs are planning on using the same hardware for DSG and lunar surface operations.

Two different communication standards will be used to support the unique needs of EVA communications. This section will address the low rate, high reliability, robust communications between the DSG and EVAs (same set of standards and protocols will be used for EVA-Rover/habitat communications on lunar surface). The next section, 3.2.2.5, will address the non-critical, high rate communications between DSG and EVAs as well as other users and applications.

3.2.2.4.1 DSG- EVA COMMUNICATIONS – FREQUENCY, NUMBER OF USERS

Comm-187: DSG shall use 410 MHz – 420 MHz (UHF), TBR-3, frequency band to communicate with EVAs.

Rationale: UHF signal characteristics maximizes coverage around obstacles, provides immunity to fading, and provides some penetration through structures making it highly suitable to support robust, high reliability, low rate communications. (High rate communications would not be suitable at this band since it requires higher size, weight and power than other frequency bands).

Comm-188: EVAs shall use 410 MHz – 420 MHz (UHF), TBR-3, frequency band to communicate with DSG.

Rationale: UHF signal characteristics maximizes coverage around obstacles, provides immunity to fading, and provides some penetration through structures making it highly suitable to support robust, high reliability, low rate communications. (High rate communications would not be suitable at this band since it requires higher size, weight and power than other frequency bands).

Comm-189: DSG – EVA communication system shall support simultaneous communications between 5 users.

Rationale: There are 5 users of this system at any given time (4 EVAs and DSG; and on the lunar surface, 4 EVAs and a rover/habitat). The EVA crew members need to be able to communicate with each other and the DSG/rover/habitat.

3.2.2.4.2 DSG – EVA COMMUNICATION LINK – SIGNAL CHARACTERISTICS

TBD-2 (defining standards for signal modulation, coding, etc. is forward work)

3.2.2.4.3 DSG – EVA COMMUNICATION LINK – NETWORK

Comm-190: DSG – EVA communication system shall use frame and network control architecture similar to the International Space Station Space-to-Space Communication System (SSCS) (TBR-4).

Rationale: The ISS SSCS provides for simultaneous communications between ISS and 4 other users for ranges up to 7 km. The system uses a Time Division Multiple Access (TDMA) architecture with 5 user slots separated by a guard band to allow for propagation delays. Any user can enter the network and establish a slot that other users synchronize to and setup their own transmissions.

3.2.2.4.4 DSG – EVA COMMUNICATIONS: SECURITY

TBD-3 (determining security needs and requirements/standards is forward work)

3.2.2.5 DSG – WIRELESS COMMUNICATION LINKS

Wireless communication networks provides communications within the DSG as well as external to the DSG. There are many users and applications for wireless communications (payload data transfer, camera images, wireless sensing for monitoring, radio frequency identification (RFID) based inventory management, etc.) This section defines the protocols and standards for wireless communications. (Standards and products for wireless communications are rapidly evolving as consumer demands call for more capability and newer technologies. Therefore, wireless standards called out today may become obsolete by the time the DSG is assembled and operational --- therefore, this section should be updated as the newer standards come out, have viable implementations, have applicability to DSG, and are agreed to by the all the international partners.)

Comm-191: DSG wireless systems shall use the following enumerated standards for wireless communications:

1. Access point(s) supporting clients conforming to version IEEE 802.11n (TBR-8) in the 2.4GHz unlicensed band to provide wireless network extension inside and outside the DSG. Operational constraints can be used to mitigate any interference issues caused by the use of 2.4GHz band for external wireless communications during DSG-VV rendezvous, proximity operations and docking.
2. Access point(s) supporting clients conforming to versions IEEE 802.11n and 802.11ac (TBR-9) in the 5GHz unlicensed band to provide wireless network extension inside and outside the DSG.
3. RFID based systems shall follow the protocols and standards provided in CCSDS Spacecraft Onboard Interface Services – RFID Based Inventory Management Systems, Recommended Practice, CCSDS 881.0-M-1 (TBR-10) to provide RFID services within the DSG.
4. RFID based systems shall use the 902-928 MHz ISM band (TBR-10) to provide RFID services within the DSG.
5. RFID based systems shall support tags conforming to TBD-6 to provide RFID services inside the DSG. (Note: EPC Global Class 1 Generation 2 RFID, version 1.2.0 (TBR-10) based on CCSDS 881.0-M-1 are currently used in many systems)
6. Gateway for Bluetooth supporting devices conforming to Bluetooth version 4.0 (Classic and BLE) in the 2.4GHz unlicensed band to provide services inside the DSG (TBR-11).
7. Access point(s) supporting clients conforming to at least version IEEE 802.11ah (TBR-12) in the 900MHz unlicensed band to provide wireless network extension outside the DSG.
8. LTE eNodeB(s) supporting UEs conforming to Release 13 (TBR-13) in a licensed band to provide gateway network extension inside and outside the DSG.

Rationale: The identified standards 802.11n/ac, Bluetooth/BLE, RFID support development of a wide range of non-critical application classes *using durable markets for commercial off-the-shelf (COTS) hardware from a large pool of vendors and supported by sizeable development communities. Applications range from streaming high-definition video, to wearables, to passive sensors or inventory tags. 802.11ah offers substantial range extension, and is anticipated to be widely available before work on DSG begins. LTE can be deployed in licensed bands and has more evolved Quality of Service controls and therefore can be offered to critical applications. Products are available which support the wireless standards, and wired cameras or other sensors can also be integrated with wireless peripherals.*

3.2.2.6 DSG – LUNAR SURFACE COMMUNICATION LINKS

This section captures the standards and protocols for communications between the DSG and elements while on the lunar surface (example: rover, habitat, etc.). The elements on the lunar surface may have other communication links to Earth, relay satellites, etc. – it is not within the scope of this document to capture the standards and protocols for those links.

Lunar surface concept of operations, mission needs, etc. are still being developed by NASA and International Partners and the following sections contain drafts to provide some reference and context. Once the concept of operations, capabilities needed and IOAG's Lunar architecture get more defined, the standards in the following sections will be updated and finalized. A summary of the *draft* standards for the DSG – Lunar surface links is given in Table 3.2.2.6-1.

TABLE 3.2.2.6-1 SUMMARY OF STANDARDS FOR DSG – LUNAR SURFACE RF LINK

	Frequency Bands[1]	Modulation[2]	Coding[3]	Space Data Link Protocol	Space Data Link Security	Ranging
DSG – Lunar Surface	22.55-23.15 GHz	• OQPSK - Modulation on suppressed carrier (Note: use of Proximity-1 protocol is being considered for this link – however, it has only been implemented at UHF. Unclear what, if any, changes need to be made to get it to work at Ka-band)	LDPC[3, 6]: • Coding rates: - $^1/_2$, $^2/_3$, $^4/_5$, $^7/_8$ • Codeblock size: - 2048 octets (for rates $^1/_2$, $^2/_3$, $^4/_5$) - 1020 octets (for rate $^7/_8$) (Note: use of Proximity-1 protocol is being considered for this link – however, it has only been implemented at UHF. Unclear what, if any, changes need to be made to get it to work at Ka-band)	AOS[4], USLP[5] • AOS frame size: - 2048 octets and 64 bit ASM (for rates $^1/_2$, $^2/_3$, $^4/_5$) - 1020 octets and 32 bit ASM (for rate $^7/_8$) (Note: use of Proximity-1 protocol is being considered for this link – however, it has only been implemented at UHF. Unclear what, if any, changes need to be made to	CCSDS Space Data Link Security Protocol[8] (Note: use of Proximity-1 protocol is being considered for this link – however, it has only been implemented at UHF. Unclear what, if any, changes need to be made to get it to work at Ka-band)	None

				get it to work at Ka-band)		
Lunar Surface to DSG	25.5-27.0 GHz	• OQPSK Modulation on suppressed carrier (Note: use of Proximity-1 protocol is being considered for this link – however, it has only been implemented at UHF. Unclear what, if any, changes need to be made to get it to work at Ka-band)	LDPC[3,6]: • Coding rates: - 1/2, 2/3, 4/5, 7/8 • Codeblock size: - 2048 octets (for rates 1/2, 2/3, 4/5,) - 1020 octets (for rate 7/8) (Note: use of Proximity-1 protocol is being considered for this link – however, it has only been implemented at UHF. Unclear what, if any, changes need to be made to get it to work at Ka-band)	AOS[4], USLP[5] • AOS frame size: - 2048 octets and 64 bit ASM (for rates 1/2, 2/3, 4/5,) - 1020 octets and 32 bit ASM (for rate 7/8) (Note: use of Proximity-1 protocol is being considered for this link – however, it has only been implemented at UHF. Unclear what, if any, changes need to be made to get it to work at Ka-band)	CCSDS Space Data Link Security Protocol[8] (Note: use of Proximity-1 protocol is being considered for this link – however, it has only been implemented at UHF. Unclear what, if any, changes need to be made to get it to work at Ka-band)	None

25. SFCG 32-2R1 Communication Frequency Allocations and Sharing in the Lunar Region.
26. CCSDS 401.0-B-27 Radio Frequency and Modulation Systems--Part 1: Earth Stations and Spacecraft. Blue Book.
27. CCSDS 131.0-B-3 TM Synchronization and Channel Coding. Blue Book.
28. CCSDS 732.0-B-3 AOS Space Data Link Protocol. Blue Book.
29. CCSDS 732.1-R-3.1 Unified Space Data Link Protocol. Red Book. November 2017, currently undergoing publication.
30. CCSDS (TBD Reference) Coding & Synchronization Sub-layer High Rate Uplink Protocol for AOS & USLP.
31. CCSDS 414.1-B-2 Pseudo-Noise (PN) Ranging Systems. Blue Book.

CCSDS 355.0-B-1 Space Data Link Security Protocol. Blue Book.

3.2.2.6.1 FREQUENCY FOR DSG-LUNAR SURFACE LINK

Comm-192: DSG shall use 22.55 – 23.15 GHz (TBR-6) frequency band to transmit signals to the lunar surface element on the DSG-Lunar Surface RF link.

Rationale: Use of near-Earth Ka-band since it is more efficient than, S-band or UHF. ITU and CCSDS/SFCG recommendations has Ka-band allocated for communications between lunar orbit and lunar surface. It does not have X-band in its recommendations for communications between lunar orbit and lunar surface communications.

Comm-193: Lunar Surface element shall use 22.55 – 23.15 GHz (TBR-6) frequency band to receive signals from the lunar surface element on the DSG-Lunar Surface RF link.

Rationale: Use of near-Earth Ka-band since it is more efficient than, S-band or UHF. ITU and CCSDS/SFCG recommendations has Ka-band allocated for communications between lunar orbit and lunar surface. It does not have

X-band in its recommendations for communications between lunar orbit and lunar surface communications

Comm-194: Lunar surface element shall use 25.5 – 27.0 GHz (TBR-6) frequency band to transmit signals to the DSG on the DSG-Lunar Surface link.

Rationale: Use of near-Earth Ka-band or X-band since it is more efficient than S-band or UHF. Currently ITU and CCSDS/SFCG recommendations has Ka-band allocated for communications between lunar orbit and lunar surface. It does not have X-band in its recommendations for communications between lunar orbit and lunar surface communications.

Comm-195: DSG shall use 25.5 – 27.0 GHz (TBR-6) frequency band to receive signals from the DSG on the DSG-Lunar Surface link.

Rationale: Use of near-Earth Ka-band or X-band since it is more efficient than S-band or UHF. Currently ITU and CCSDS/SFCG recommendations has Ka-band allocated for communications between lunar orbit and lunar surface. It does not have X-band in its recommendations for communications between lunar orbit and lunar surface communications

3.2.2.6.2 MODULATION FOR THE DSG-LUNAR SURFACE LINK

(Note: use of Proximity-1 protocol is being considered for this link – however, the standard has been written UHF centric and it has been implemented at UHF (Reference Proximity-1 Space Link Protocol--Physical Layer**,** CCSDS 211.1-B-4). *Only NASA and ESA have developed systems using Proximity-1 for communications between Mars surface assets and a Mars Orbiter for lower rate data transfers than what is being anticipated for the DSG – Lunar surface applications. It is unclear what changes need to be made to get Proximity-1 to work at Ka-band and higher data rates. If Proximity-1 is updated to work with Ka-band and is selected for this link, this section will be updated as needed.)*

Comm-196: DSG and lunar surface element shall implement OQPSK with modulation on suppressed carrier to transmit signals as described in *Radio Frequency and Modulation Systems--Part 1: Earth Stations and Spacecraft,* Section 2, CCSDS 401.0-B-27, Blue Book on the DSG-Lunar Surface link. (TBR-23)

Rationale: OQPSK with modulation on suppressed carrier provides spectral efficiency and interoperability between DSG and NASA/IP/etc. assets, provides spectrum efficiency and meets spectrum constraints imposed by SFCG and NTIA.

Comm-197: DSG and lunar surface element shall implement OQPSK with modulation on suppressed carrier to receive signals as described in *Radio Frequency and Modulation Systems--Part 1: Earth Stations and Spacecraft,* Section 2, CCSDS 401.0-B-27, Blue Book on the DSG-Lunar Surface link. (TBR-23).

Rationale: OQPSK with modulation on suppressed carrier provides spectral efficiency and interoperability between DSG and NASA/IP/etc. assets, *provides spectrum efficiency and meets spectrum constraints imposed by SFCG and NTIA.*

3.2.2.6.3 CODING AND SYNCHRONIZATION FOR THE DSG-LUNAR SURFACE LINK

(Note: use of Proximity-1 protocol is being considered for this link – however, the standard has been written UHF centric and it has been implemented at UHF. (Reference Proximity-1 Space Link Protocol—Coding and Synchronization Sublayer**,** CCSDS 211.2-B-2). *Only NASA and ESA have developed systems using Proximity-1 for communications between Mars surface assets and a Mars Orbiter for lower rate data transfers than what is being anticipated for the DSG – Lunar surface applications. It is unclear what changes need to be made to get Proximity-1 to work at Ka-band and higher data rates. If Proximity-1 is updated to work with Ka-band and is selected for this link, this section will be updated as needed.)*

Comm-198: DSG and lunar surface element shall use CCSDS Low Density Parity Codes, rate ½, rate $^{2}/_{3}$, rate $^{4}/_{5}$, or rate $^{7}/_{8}$ for encoding data as defined in Section 7, TM Synchronization and Channel Coding CCSDS 131.0-B-3 on the DSG-Lunar Surface link. (TBR-24).

Rationale: Coding gain provided by LDPC codes is ~2dB more than that provided by concatenated Reed-Solomon/convolutional codes. Can implement one, two, three or all four of the above LDPC codes based on data rates and other system needs/constraints.

Comm-199: DSG and lunar surface element shall use CCSDS Low Density Parity Codes, rate ½, rate $^{2}/_{3}$, rate $^{4}/_{5}$, and rate $^{7}/_{8}$ for decoding data as defined in Section 7, TM Synchronization and Channel Coding CCSDS 131.0-B-3 on the DSG-Lunar Surface link. (TBR-24).

Rationale: Coding gain provided by LDPC codes is ~2dB more than that provided by concatenated Reed-Solomon/convolutional codes.

Comm-200: DSG and lunar surface element shall apply the Attached Sync Marker (ASM) defined in Section 9, *TM Synchronization and Channel Coding* CCSDS 131.0-B-3, to transmitted frames per Table 3.2.2.2-2 on the DSG-Lunar Surface link. (TBR-24)

Rationale: Use of the 64-bit CCSDS frame sync pattern identified as ASM for rate ½, rate $^{2}/_{3}$, or rate $^{4}/_{5}$ and the 32-bit CCSDS frame sync pattern identified for rate $^{7}/_{8}$ *LDPC Coded Data provides the receiver the ability to synchronize at the start of a FEC code block frame and will ensure interoperability between DSG and NASA/IP assets. Using the same 64 bit/32 bit ASM for non-FEC coded block frames will maintain a common frame structure for all coded and uncoded frames, which will reduce Program implementation complexity and costs.*

Comm-201: DSG and lunar surface element shall use the Attached Sync Marker (ASM) defined in Section 9, *TM Synchronization and Channel Coding* CCSDS

131.0-B-3 for synchronization of received frames per Table 3.2.2.2-2 on the DSG-Lunar Surface link. (TBR-24).

Rationale: Use of the 64-bit CCSDS frame sync pattern identified as ASM for rate ½, rate $^2/_3$, or rate $^4/_5$ and the 32-bit CCSDS frame sync pattern identified for rate $^7/_8$ *LDPC Coded Data provides the receiver the ability to synchronize at the start of a FEC code block frame and will ensure interoperability between DSG and NASA/IP assets. Using the same 64 bit/32 bit ASM for non-FEC coded block frames will maintain a common frame structure for all coded and uncoded frames, which will reduce Program implementation complexity and costs.*

Comm-202: DSG and lunar surface element shall use bit randomization techniques in accordance with CCSDS 131.0-B-3 for randomization of transmitted data streams on the DSG-Lunar Surface link. (TBR-24).

Rationale: Use of bit randomization techniques as specified in CCSDS 131.0-B-2 will ensure the proper bit synchronization process and interoperability between DSG and NASA/IP assets

Comm-203: DSG and lunar surface element shall use bit derandomization techniques in accordance with CCSDS 131.0-B-3 for derandomization of received data streams on the DSG-Lunar Surface link. (TBR-24)

Rationale: Use of bit randomization techniques as specified in CCSDS 131.0-B-2 will ensure the proper bit synchronization process and interoperability between DSG and NASA/IP assets

Comm-204: DSG and lunar surface element shall use Non-Return-to-Zero-Level (NRZ-L) encoding for transmission of data streams on the DSG-Lunar Surface link. (TBR-24).

Rationale: NRZ-L is required to allow LDPC FEC codes to operate at maximum efficiency, producing the highest possible amount of coding gain. NRZ-L symbol L format encoding has better E_b/N_o *performance than differential symbol format encoding like Non-Return-to-Zero-Mark (NRZ-M). Phase ambiguity resolution will be resolved by using a frame Attached Sync Marker (ASM) rather than using differential encoding like NRZ-M.*

Comm-205: DSG and lunar surface element shall use the ASM for resolution of symbol phase ambiguity of received data streams on the DSG-Lunar Surface link. (TBR-24)

Rationale: Phase ambiguity resolution will be resolved by using a frame ASM rather than using differential symbol format encoding like Non-Return-to-Zero-Mark (NRZ-M) since NRZ-L is needed to allow LDPC FEC codes to operate at maximum efficiency. NRZ-L also has better E_b/N_o *performance than differential encoding like NRZ-M.*

3.2.2.6.4 DATA LINK LAYER FOR THE DSG-LUNAR SURFACE LINK

(Note: use of Proximity-1 protocol is being considered for this link – however, the standard has been written UHF centric and it has been implemented at UHF (Reference Proximity-1 Data layer implementation as described in Space Link Protocol--Data Link Layer, CCSDS 211.0-B-5). *Only NASA and ESA have developed systems using Proximity-1 for communications between Mars surface assets and a Mars Orbiter for lower rate data transfers than what is being anticipated for the DSG – Lunar surface applications. It is unclear what changes need to be made to get Proximity-1 to work at Ka-band and higher data rates. If Proximity-1 is updated to work with Ka-band and is selected for this link, this section will be updated as needed.)*

Comm-206: DSG and lunar surface elements shall transmit data streams using data link framing as defined in CCSDS Advanced Orbiting Systems (AOS) Space Data Link Protocol, CCSDS 732.0-B-3, on the DSG-Lunar Surface link. (TBR-25).

Rationale: CCSDS 732.0-B-3 provides the structure for frame construction. Need to follow this standard to ensure interoperability between DSG and NASA/IP assets.

NOTE: CCSDS is working to baseline the Unified Space Link Protocol (USLP). Once the USLP blue book is baselined and all partners agree to implement it, this standard will be updated with the USLP blue book.

Comm-207: DSG and lunar elements shall receive data streams using data link framing as defined in CCSDS Advanced Orbiting Systems (AOS) Space Data Link Protocol, CCSDS 732.0-B-3, on the DSG-Lunar Surface link. (TBR-25).

Rationale: CCSDS 732.0-B-3 provides the structure for frame construction. Need to follow this standard to ensure interoperability between DSG and NASA/IP assets.

NOTE: CCSDS is working to baseline the Unified Space Link Protocol (USLP). Once the USLP blue book is baselined and all partners agree to implement it, this standard will be updated with the USLP blue book.

3.2.2.6.5 NETWORK LAYERS AND ABOVE FOR THE DSG-LUNAR SURFACE LINK

(Note: use of Proximity-1 protocol is being considered for this link – however, the standard has been written UHF centric and it has been implemented at UHF. Only NASA and ESA have developed systems using Proximity-1 for communications between Mars surface assets and a Mars Orbiter for lower rate data transfers than what is being anticipated for the DSG – Lunar surface applications. It is unclear what changes need to be made to get Proximity-1 to work at Ka-band and higher data rates. If Proximity-1 is updated to work with Ka-band and is selected for this link, this section will be updated as needed.)

3.2.2.6.5.1 NETWORK LAYER

Comm-208: DSG and lunar elements shall transmit and receive data streams using the CCSDS Encapsulation Service as defined in CCSDS 133.1-B-2 when communicating over CCSDS Data Link Layer Protocols on the DSG-Lunar Surface link. (TBR-26).

Rationale: CCSDS Data Link Layers are designed to carry either CCSDS Space Packets or Encapsulation Packets. The Encapsulation Service provides the compatibility between the higher layer data units and the CCSDS Data Link Layers.

Comm-209: DSG and lunar elements shall transmit and receive IP packets using the CCSDS IP over CCSDS standard CCSDS 702.1-B-1 when using IP packets over CCSDS Data Link Layers on the DSG-Lunar Surface link. (TBR-26).

Rationale: This allows IP packet use interoperability over CCSDS links.

Comm-210: DSG and lunar elements shall use IP as specified in IPv4 (RFC 791) or IPv6 (RFC 8200) (TBR-16) as a network layer on the DSG-Lunar Surface link. (TBR-26).

Rationale: IP provides for network layer services over interfaces that have low delay (under 5 sec (TBD)) and an expectation of real time end-to-end connectivity. Use of IP allows for maximum leverage of terrestrial networking developments under appropriate circumstances. IPv4-based technology is widely available in the commercial market. IPv6-only stack provides advantages such as increased security and more efficient routing. IPv6 technology is not as readily available.

3.2.2.6.5.2 TRANSPORT LAYER

Comm-211: DSG and lunar elements shall (TBR-7) implement Licklider Transmission Protocol (LTP) as specified in CCSDS Licklider Transmission Protocol for CCSDS, CCSDS 734.1-B-1 on the DSG-Lunar Surface link. (TBR-26).

Rationale: LTP is a reliable point-to-point transport protocol, over which the Bundle Protocols will run. LTP is not expected to be used for all links, but was designed for long-haul links with high delay.

Comm-212: DSG and lunar elements shall implement Transmission Control Protocol (TCP) as specified in RFC 793 on the DSG-Lunar Surface link. (TBR-26).

Rationale: TCP is a reliable transport protocol for use on IP networks.

Comm-213: DSG and lunar elements shall implement User Datagram Protocol (UDP) as specified in RFC 768 on the DSG-Lunar Surface link. (TBR-26).

Rationale: UDP provides best effort transport protocol for use on IP networks.

3.2.2.6.5.3 BUNDLE AND BUNDLE CONVERGENCE LAYER

Comm-214: DSG and lunar elements shall implement Delay Tolerant Networking Bundle Protocol as specified in CCSDS Bundle Protocol Specification, CCSDS 734.2-B-1 on the DSG-Lunar Surface link. (TBR-26).

Rationale: Provide lunar network and inter-planetary network functionality, e.g., network addressing, routing, and QoS management, in end-to-end communications environment of intermittent connectivity. When functioning as a relay, the DSG must have the capability to multiplex/demultiplex capability to deal with multiple data streams from multiple sources over heterogeneous links.

Comm-215: DSG and lunar elements should (TBR-18) implement the CCSDS standard "Streamlined Bundle Security Protocol" (DRAFT CCSDS 734.5-B-1) to secure DTN standard data bundles.

Rationale: Securing DTN bundles for transport is essential.

Comm-216: When DSG and lunar elements data links are not using secure DTN bundling, they should (TBR-19) provide for the option to implement Internet Protocol Security (IPSec) over IP links. IPSec is specified in RFC 6071.

Rationale: Application of IPSec to these data flows is strongly recommended to reduce mission risk when the data flows are not secured by the DTN Bundle security protocol.

Comm-217: DSG and lunar elements shall implement the Licklider Transmission Protocol Convergence Layer Adapter as specified in CCSDS 734.2-B-1 on the DSG-Lunar Surface link. (TBR-26).

Rationale: In cases when Bundle Protocol is used over long delay or environments not conducive to IP-based convergence layers, LTP can provide reliable delivery. LTP may optionally be used over UDP [TBR]

Comm-218: DSG and lunar elements shall implement the Encapsulation Convergence Layer Adapter as specified in CCSDS 734.2-B-1 on the DSG-Lunar Surface link. (TBR-26).

Rationale: In circumstances when Bundle Protocol is used without a transport layer protocol, the encapsulation convergence layer adapter will allow bundles to be directly encapsulated and transmitted over CCSDS link layer protocols.

Comm-219: DSG and lunar elements should implement the TCP Convergence Layer Adapter as specified in RFC 7242 (TBR-17) on the DSG-Lunar Surface link. (TBR-26).

Rationale: When a hop between DTN nodes is carried over an IP network, the TCP convergence layer will provide reliable delivery of bundles. RFC 7242 is in the experimental stage and not a finalized standard.

Comm-220: DSG and lunar elements should implement the UDP Convergence Layer Adapter as specified in CCSDS 734.2-B-1 on the DSG-Lunar Surface link. (TBR-26).

Rationale: When a hop between DTN nodes is carried over an IP network, the UDP convergence layer will provide unreliable delivery of bundles. Addition of LTP over the UDP convergence layer may be used to provide reliable bundle delivery.

3.2.2.6.5.4 APPLICATION LAYER

Comm-221: All applications transferring data over the DSG - lunar element interface shall use either DTN Bundle Protocol or IP as specified above on the DSG-Lunar Surface link. (TBR-26).

Rationale: This will allow all data flows to be routable by intermediate nodes. Any application that expects to flow data to and from Earth either directly or relayed should use BP to accommodate delays or end-to-end link availability. Though IP may work in some Cislunar cases, use of BP will allow the application to also function in deep space cases.

Comm-222: DSG and lunar elements shall use CCSDS File Delivery Protocol Class 1 and Class 2 as defined in *CCSDS File Delivery Protocol (CFDP),* CSDS 727.0-B-4 transmit and receive application layer files on the DSG-Lunar Surface link. (TBR-26).

Rationale: Provide reliable, accountable transfer of files.

Comm-223: DSG and lunar elements should (TBR-14) use asynchronous message service (AMS) as defined in Asynchronous Message Service (AMS) CCSDS 735.1-B-1 to transmit and receive messages on the DSG-Lunar Surface link. (TBR-26).

Rationale: provides a standard, reusable infrastructure for the exchange of information among data system modules in a manner that is simple to use, highly automated, flexible, robust, scalable, and efficient.

3.2.2.6.6 SECURITY FOR THE DSG-LUNAR SURFACE LINK

(Note: use of Proximity-1 protocol is being considered for this link – however, the standard has been written UHF centric and it has been implemented at UHF. Only NASA and ESA have developed systems using Proximity-1 for communications between Mars surface assets and a Mars Orbiter for lower rate data transfers than what is being anticipated for the DSG – Lunar surface applications. It is unclear what changes need to be made to get Proximity-1 to work at Ka-band and higher data rates. If Proximity-1 is updated to work with Ka-band and is selected for this link, this section will be updated as needed.)

The following define the security standards to ensure interoperability. The actual links & data to be protected, security & key management, etc. will be based on the International Partner agreement on security policies for the Program(s).

Comm-224: DSG and lunar surface elements shall implement CCSDS Cryptographic Algorithms, *CCSDS 352.0-B-1*, Advanced Encryption Standard (AES), for encryption and decryption of data exchanges on the DSG-Lunar Surface link. (TBR-27).

Rationale: AES is the algorithm of choice for Federal Information Systems per FIPS PUB 197.

Comm-225: DSG and lunar surface elements shall implement the Advanced Encryption Standard specifically the Galois Counter Mode (AES-GCM) algorithm per NIST SP 800-38D, with 256-bit keys, 96-bit Initialization Vectors (IVs), and with authentication tag lengths of 128 bits truncated to 64 bits for data exchanges on the DSG-Lunar Surface link. (TBR-27) *Programs need to assess the level of Security Information Assurance and Risks for non-command and control links, and shall select an appropriate AES mode commensurate with those risks, and implement MOU/MOA agreements to handle applicable circumstances*.

Rationale: The use of AES-GCM is an efficient implementation for encryption and authentication of data and information exchanges.

Comm-226: DSG and lunar surface elements shall implement link layer security as specified by CCSDS 355.0-B-1, Space Data Link Security Protocol for data exchanges on the DSG-Lunar Surface link. (TBR-27).

Rationale: Use CCSDS standards to ensure interoperability and compatibility.

Comm-227: DSG and lunar surface elements shall implement authentication as specified by *CCSDS 355.0-B-1* CCSDS Cryptographic Algorithms for data exchanges on the DSG-Lunar Surface link. (TBR-27).

Rationale: DSG needs to support authentication in addition to encryption.

Comm-228: DSG and lunar surface elements shall be able to enable or disable encryption to support contingency operations on the DSG-Lunar Surface link. (TBR-27).

Rationale: DSG needs to be able to turn off encryption to support spacecraft recovery, contingency modes, etc.

Comm-229: DSG and lunar surface elements shall employ key management techniques as defined in TBD-1 on the DSG-Lunar Surface link. (TBR-27). (TBD-1 could be SDLS Extended Procedures standard (draft CCSDS 355.1-B-1) as noted below)

Rationale: This requirement ensures that keys are managed in an interoperable manner.

Note: CCSDS is working on the SDLS Extended Procedures standard (CCSDS 355.1-B-1)*. Once the standard is baselined and all partners agree to implement it, this standard will be updated with the Symmetric Key Management blue book.*

3.3 PERFORMANCE

The link specific performance parameters and requirements (example: data rates, bit-error rates, received power, antenna gain, etc.) will be captured in the interface control documents (ICDs) between the respective end points. The standards required for interoperability are defined in this version of the document (provides the necessary requirements for interoperability). The next version of the document will include the details at specific protocol stack levels and meeting them will be sufficient for interoperability – in the course of defining those details, if there is a need to specify data rates (or any other parameter) as part of the protocol stack, it will be added to this document.

For reference, anticipated data rates for the different links and a basis of estimation for these data rates is given in Appendix F.

Comm-230: All DSG communication links shall have a minimum 3 dB (TBR-5) link margin.

Rationale: Having a certain amount of link margin ensures that the communication link can still be established in case there are additional degradations during off-nominal or contingency situations.

Comm-231: All DSG uncoded communication links shall have a channel bit error rate of less than or equal to 10^{-6} (TBR-ber).

Rationale: A bit error rate requirement is one factor in providing a robust communication channel. Where we measure the bit error rate and what should that value be needs to be determined for this application.

Comm-232: All DSG coded communication links shall have a frame error rate less than or equal to 10^{-7}(TBR-fer)

Rationale: A bit error rate requirement is one factor in providing a robust communication channel. However, for links using block codes, frame error rate better performance measures. The value(s) of frame error rate specified for this application needs to be determined.

3.4 VERIFICATION AND TESTING

The detailed flowdown of the interface standards will be captured in the ICDs between the respective endpoints. The corresponding verification requirements will be defined and described in the ICDs. Majority of the requirements will be verified using a combination of interface/compatibility testing and analysis at the subsystem and system level.

Once the ICDs are developed, this section will either be updated to reference the respective ICDs for the verification requirements or captured in this section.

TBD-4

4.0 FUTURE TOPICS FOR POSSIBLE STANDARDIZATION

4.1 DETAILS TO PROVIDE "SUFFICIENCY FOR INTEROPERABILITY"

The protocols and standards currently defined in this standard are necessary to provide interoperability between systems and elements. The protocols and standards have different options and protocol stack dependent implementation details need to be further specified to ensure that the interface is sufficiently defined to be interoperable. Future revisions of this standard will provide the requirements to meet the necessary and sufficient conditions for interoperability.

4.2 EXTENSION OF STANDARDS AND PROTOCOLS FOR DEEP SPACE MISSIONS

The ICSIS document addresses standards and protocols for both DSG and DST. The current version of the document does not explicitly address standards and protocols for the deep space missions. Every effort is being made to ensure compatibility and extensibility of protocols and standards selected for cislunar missions to deep space exploration missions. Future revisions of this document will be include any modifications to the protocols and standards for deep space applicability. For example, the frequencies defined for the cislunar applications are per the near-Earth spectrum allocations. The frequencies for deep space excursions need to be added to be compliant with deep space spectrum allocations.

4.3 CONTINGENCY COMMUNICATIONS

The interoperability standards for contingency/emergency communications are currently being discussed and worked at the IOAG level. Once the standards for contingency communications and agreed to by all the partners, it will be included in this Interoperability Standards document. Some guidance on the current thinking of the IOAG working group is currently provided in this section

4.4 DSG-LUNAR SURFACE COMMUNICATIONS

Lunar surface concept of operations, mission needs, etc. are still being developed by NASA and the International Partners. The sections under DSG-Lunar communications contain some guidance on current thinking to provide some reference and context. Once the concept of operations, capabilities needed and IOAG's Lunar architecture get more defined, the standards in the corresponding sections will be updated and finalized.

4.5 END-TO-END COMMUNICATIONS WITH MISSION CONTROL CENTERS

The current version of the document does not include any standards or protocols that specifies explicit requirements for the operation of space links, from the DSG Mission Control Center, using Space Link Extension (SLE) services (such as Forward-Communication Link Transmission Units (F-CLTU), etc.) and Cross Support Transfer Services (CSTS) (e.g., Monitor Data-CSTS) protocols. Nor are there explicit requirements for space link layer capability to multiplex/de-multiplex multiple data streams to/from multiple destinations/sources in supporting DTN service. These will be addressed in future revisions of this document.

APPENDIX A ACRONYMS AND ABBREVIATIONS

AES	Advanced Encryption Standard
AMS	Asynchronous Message Service
AOS	Advanced Orbiting Systems
API	Application Program Interface
ASM	Attached Sync Marker
B-PDU	Bitstream Protocol Data Units
BER	Bit Error Rate
BPSK	Binary Phase Shift Keying
C&T	Communications & Tracking
CADU	Channel Access Data Unit
CCSDS	Consultative Committee on Space Data Systems
CFDP	CCSDS File Delivery Protocol
CMD	Command
CSMA	Carrier Sense Multiple Access
CSTS	Cross Support Transfer Services
CWER	Codeword Error Rate
Codec	Coding/Decoding
dB	Decibel
DES	Digital Encryption Standard
DFE	Direct From Earth
DG1	Data Group 1
DSN	Deep Space Network
DTE	Direct To Earth
DTN	Disruption Tolerant Networking
EIRP	Effective Isotropic Radiated Power
ENCAP	Encapsulation
EVA	Extravehicular Activity
Eb/No	Energy per Bit-To-Noise Power Spectral Density Ratio
F-CLTU	Forward-Communication Link Transmission Units
FEC	Forward Error Correction
FIPS	Federal Information Processing Standards
FIPS PUB	Federal Information Processing Standard Publication
FLR	Frame Loss Rate
FM	Frequency Modulation
GCM	Galois/Counter Mode
GPS	Global Positioning System
GSFC	Goddard Space Flight Center
GbE	Gigabit Ethernet
HD	High Definition

HDR	High Data Rate
HDTV	High Definition Television
HR	High Rate
HSF	Human Space Flight
HTTP	Hypertext Transfer Protocol
Hz	Hertz
I	Inphase
ICD	Interface Control Document
IEEE	Institute of Electrical and Electronics Engineers
IOAG	Interagency Operations Advisory Group
ISO	International Standards Organization
ISS	International Space Station
ITU	International Telecommunications Union
IV	Initialization Vector
JPEG	Joint Photographic Experts Group
kbps	kilobits per second
kHz	Kilohertz
km	Kilometer
ksps	kilo symbols per second
LDPC	Low Density Parity Check
LDR	Low Data Rate
LEO	Low Earth Orbit
LHCP	Left Hand Circular Polarization
LSB	Least Significant Bit
LVL	Level
m	meter
M-PDU	Multiplexed Protocol Data Units
MA	Multiple Access
MCB	Multilateral Coordination Board
MHz	megahertz
MPCV	Multi-Purpose Crew Vehicle
MSB	Most Significant Bit
Mbps	Megabits per second
Msps	Mega symbols Per Second
N/A	Not Applicable
NASA	National Aeronautics and Space Administration
NEN	Near Earth Network
NIST	National Institute of Standards and Technology
NRZ-L	Non-Return to Zero Level
NRZ-M	Non-Return to Zero Mark
NDS	Noise Spectral Density
ns	nanosecond

NTIA	National Telecommunications and Information Administration
PCM	Pulse Code Modulation
PFD	Power Flux Density
PHY	Physical Layer
PM	Phase Modulation
PN	Pseudo Noise
PSK	Phase Shift Keying
PTP	Point-to-Point
Q	Quadrature
QPSK	Quadrature Phase Shift Keying
QoS	Quality of Service
RCV	Receive
RF	Radio Frequency
RFI	Radio Frequency Interface
RHCP	Right-Hand Circular Polarization
RPOD	Rendezvous-Proximity Operation-Docking
RS	Reed Solomon
SATCOM	Satellite Communications
SCaN	Space Communications and Navigation
SE&I	Systems Engineering and Integration
SI	International System of Units
SLE	Space Link Extension
SN	Space Network
SNR	Signal-to-Noise Ratio
SNUG	Space Network Users Guide
SQPN	Staggered Quadrature Phase Noise
SQPSK	Staggered Quadrature Phase Shift Keying
TBD	To Be Determined
TBR	To Be Resolved
TLM	Telemetry
TM	Telemetry
TRP	Total Receive Power
TRP/NSD	Total Receive Power/Noise Spectral Density
UER	Undetected Codeword Error Rate
UHF	Ultra-High Frequency
UQPSK	Unbalanced Quad Phase Shift Keying
US	United States
USN	Universal Space Network
UTC	Coordinated Universal Time
VC	Virtual Channel
VCA	Virtual Channel Access

VCP	Virtual Channel Packet
VHF	Very High Frequency
VOIP	Voice Over IP
VSWR	Voltage Standing Wave Ratio
WSC	White Sands Complex
XMIT	Transmit

APPENDIX B GLOSSARY

Bent pipe

Header of data is read and processed or modified, as needed, and (header + data) sent on to the correct user. Actual user or payload data is not processed or modified.

DSG-Ground

The term used for the Earth side of the interface that performs the required function. This could be ground station(s) (examples: Deep space network, near-earth network, etc.) or it could be a combination of ground station(s) and control center, etc. The ground station(s) used could be any of the NASA ground stations, an international partner ground station, a commercial or other agency ground station or a combination of one or more available ground stations.

Relay

Forward data from other DSG elements /payloads on to its destination, store data if link is not available.

APPENDIX C OPEN WORK

Table C-1 lists the specific To Be Determined (TBD) items in the document that are not yet known. The TBD is inserted as a placeholder wherever the required data is needed and is formatted in bold type within brackets. The TBD item is numbered based on the section where the first occurrence of the item is located as the first digit and a consecutive number as the second digit (i.e., <TBD 4-1> is the first undetermined item assigned in Section 4 of the document). As each TBD is solved, the updated text is inserted in each place that the TBD appears in the document and the item is removed from this table. As new TBD items are assigned, they will be added to this list in accordance with the above described numbering scheme. Original TBDs will not be renumbered.

TABLE C-1 TO BE DETERMINED ITEMS

TBD	Section	Description
TBD-1	3.2.2.2.1.7 3.2.2.2.2.1.6 3.2.2.6.6	No standard yet for symmetric key management – CCSDS is working on a standard for this. Replace TBD-1 when this standard gets baselined and all International partners agree to implement it.
TBD-2	3.2.2.4.2	Need to define signal characteristics for DSG-EVA communications
TBD-3	3.2.2.4.4	Need to determine security needs and requirements/standards for DSG-EVA communications
TBD-4	3.4	This version of the document does not have the verification requirements completed. Detailed verification requirements will be defined in the respective ICDs between the two end-points. Future revisions of this document will include pointers to the location of the verification requirements.
TBD-5	3.2.2.2.2.2	Optical Standards are still being worked by CCSDS. Once they have been finalized and agreed to by the International partners, they will be added to the document
TBD-6	3.2.2.5	RFID tag encoding standard needs to be added
TBD-7	3.2.1.3	Providing metadata with imagery is open since there is not an international standard for it. There is a NASA STD 2822 for it
TBD-8	3.2.2.2.3	Need to develop contingency communications standards
TBD-9		

Table C-2 lists the specific To Be Resolved (TBR) issues in the document that are not yet agreed to. The TBR is inserted as a placeholder wherever the required data is needed and is formatted in bold type within brackets. The TBR issue is numbered based on the section where the first occurrence of the issue is located as the first digit and a consecutive number as the second digit (i.e., <TBR 4-1> is the first unresolved issue assigned in Section 4 of the document). As each TBR is resolved, the updated text is inserted in each place that the TBR appears in the document and the issue is removed from this table. As new TBR issues are assigned, they will be added to this list in accordance with the above described numbering scheme. Original TBRs will not be renumbered.

TABLE C-2 TO BE RESOLVED ISSUES

TBR	Section	Description
TBR-2	3.2.2.2.1.4	Need to agree on using CCSDS 506.1-B-1 Delta-DOR raw data exchange format
TBR-3	3.2.2.4	The frequency for the DSG-EVA (proximity communications) – being proposed as UHF needs to be resolved
TBR-4	3.2.2.4	ISS SSCS frame and network control architecture is proposed for the DSG-EVA communication system – this needs to be resolved within the standards team
TBR-5	3.3	Need to finalize how much link margin should be carried for DSG communication links
TBR-6	3.2.2.6.1.1	Need to resolve frequency for DSG-lunar surface element communications – Ka-band is being proposed
TBR-7	3.2.2.2.1.6.2 3.2.2.2.2.1.5.2 3.2.2.6.5.1.2	Need to resolve whether LTP is a requirement (“shall”) for cislunar operational links or it is something to “test” at cislunar and require for deep space exploration missions when the time delays are greater.
TBR-8	3.2.2.5.1	Need to resolve standards for wireless communications 802.11.xx. in 2.4 GHz band
TBR-9	3.2.2.5.1	Need to resolve standards for wireless communications 802.11.xx. in 5 GHz band
TBR-10	3.2.2.5.1	Need to resolve standards for RFID systems
TBR-11	3.2.2.5.1	Need to resolve if we want to have Bluetooth and if so, what standard to use
TBR-12	3.2.2.5.1	Need to resolve if we want to have IEEE802.11.ac and if so, what standard to use
TBR-13	3.2.2.5.1	Need to resolve if we want to have LTE and if so, what standard to use
TBR-14	3.2.2.2.1.6.4 3.2.2.2.1.5.4 3.2.2.6.5.1.4	Need to resolve if AMS is a requirement - AMS is not needed to use CFDP, and in fact, CFDP is most often without AMS.
TBR-15	3.2.2.2.2	Ka-band uplink side of interface has not yet been implemented and a minimum implementation is provided here for guidance. TBR will be removed when get agreement on the Ka-band uplink implementation by the partners.
TBR-16	3.2.2.2.1.6.1 3.2.2.2.1.5.1 3.2.2.6.5.1.1	Need to resolve between IPv4 and IPv6
TBR-17	3.2.2.2.1.6.3 3.2.2.2.1.5.3 3.2.2.3.6 3.2.2.6.5.1.3	Resolve need for TCP Convergence layer adapter
TBR-18	3.2.2.2.1.6.3 3.2.2.2.1.5.3 3.2.2.3.6 3.2.2.6.5.1.3	Resolve need to implement streamlined bundle security protocol once standards has been baselined and agreed to implementation by the partners.
TBR-19	3.2.2.2.1.6.3 3.2.2.2.1.5.3 3.2.2.3.6 3.2.2.6.5.1.3	Option to use IPSec when not using secure DTN bundling
TBR-20	3.2.2.3.6	implementation of bundle protocol, by visiting vehicles
TBR-21	3.2.2.3.6	implementation of LTP by visiting vehicles
TBR-22	3.2.2.3.6	implementation of encapsulation convergence layer adapter by visiting vehicles
TBR-23	3.2.2.6.2	modulation for lunar comm
TBR-24	3.2.2.6.3	coding and synchronization for Lunar comm

TBR-26	3.2.2.6.5	network layer and above for lunar comm
TBR-27	3.2.2.6.6	security layer for lunar comm
TBR28		
TBR-29		
TBR-30		
TBR-31		
TBR-32		
TBR-33		

APPENDIX D DATA TRANSFER DETAILS

Data Transfer between DSG and Earth

DSG – Earth (Downlink) ---- Uncrewed (periodic coverage)

1. Health and Status data
2. Engineering and Science Data
3. Caution and Warning (low latency)
4. File downloads
5. Camera images/Video (near real-time and stored)
6. Relayed health and status, etc. from other modules
7. Support Radio Frequency ranging (Radiometric tracking)

DSG to Earth (Downlink) ---- Crewed (near 24/7 towards less frequent coverage)

1. Health and Status data
2. Engineering and Science Data
3. Caution and Warning (low latency)
4. File downloads
5. Camera images/Video (near real-time and stored)
6. Relayed health and status, etc. from other elements
7. Relayed EVA data
8. Support Radiometric tracking
9. Audio (near real-time and stored)
10. Video Conferencing
11. Email, family communications, texts, etc.
12. Internet apps use

24/7 availability, low rate spacecraft TT&C links to support unplanned contingencies and spacecraft emergency (low latency)

Earth to DSG (Uplink) ---- Uncrewed (periodic coverage)

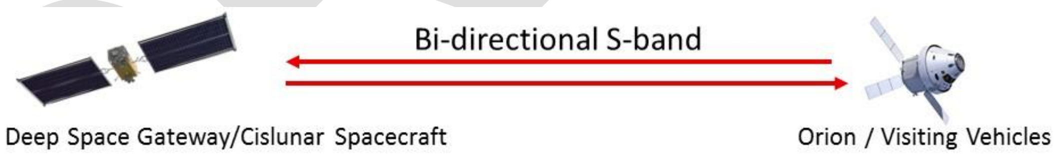
1. Commands
2. Configuration initialization and updates
3. GNC State information
4. Software updates
5. Data uploads (procedures, files, images, etc.)
6. Relayed Commands, etc. to other modules
7. Support Radio Frequency ranging (Radiometric tracking)

Earth to DSG (Uplink) ---- Crewed (near 24/7 towards less frequent coverage)

1. Commands
2. Configuration initialization and updates
3. GNC State Information
4. Software updates
5. Data uploads (procedures, files, images, etc.)
6. Relayed Commands, etc. to other modules
7. Relayed commands/information for EVAs
8. Support Radiometric tracking
9. Audio (near real-time)
10. Video Conferencing
11. Email, family communications, texts, etc.
12. Internet apps use

24/7 availability, low rate spacecraft TT&C links to support unplanned contingencies and spacecraft emergency (low latency)

Data Transfer between DSG and Visiting Vehicle (Orion)



DSG to Orion/VV ---- during Rendezvous and Docking/berthing

1. Health and Status data
2. Caution and Warning
3. Relayed health and status, etc. from other modules
4. Support Radiometric tracking
5. Audio (real-time)
6. Images

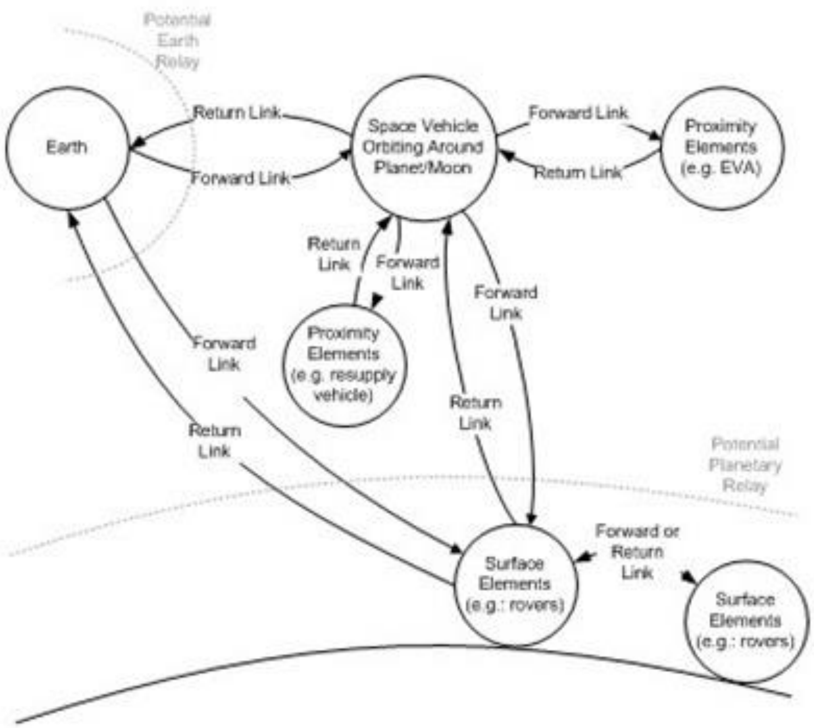
During rendezvous and docking, Orion/VV data can be relayed to ground via the DSG-Ground link as a backup to the Orion/VV-ground link

Orion/VV to DSG ---- during Rendezvous and Docking/berthing

1. Commands
2. Configuration updates
3. Data uploads (procedures, files, images, etc.)
4. Radiometric tracking
5. Audio (real-time)

During rendezvous and docking, DSG data can be relayed to ground via the Orion/VV-Ground link as a backup to the DSG-ground link

APPENDIX E FUNCTIONAL DATA FLOW – GENERIC LUNAR/PLANETARY MISSION



Note: Communication links are shown between surface elements as well as between surface elements and Earth for completeness. Definition of interoperability standards for these links are currently not within the scope of this document.

APPENDIX F DATA RATE BASIS OF ESTIMATES

Communication Link	Forward Link	Return Link	Data Rate Justification
Earth to Space Vehicle in Cislunar Orbit & Earth to Space Vehicle while on excursion to Mars (and other Deep Space Destinations)	2-10+ Mbps	10-100+ Mbps	Forward Link: Allows: • ~20 kbps for audio: 2 channels (assuming ~ 10 kbps per channel depending on compression used) • ~100 kbps for commands: (ISS has ~40kbps for commands, double to account for attached elements & surface vehicles + add 20kbps for margin) • ~100 kbps for Software uploads: Full On-Board SW Upload ~100 Mbps; Assuming 1 hour contact time with Earth and full SW upload in that 1 hour and using a factor of 4 margin gives ~100kbps • ~1-2 Mbps for mission planning: (procedures, file transfers, etc.) • ~2+ Mbps Video/imagery: minimum 1 channel 1080p HD @ 2 Mbps, more likely 5Mbps (if 4K, then 8Mbps best case or 16Mbps conservative case) • ~2+ Mbps crew communications (private medical conference, family communications, etc. (audio synchronized with video is ~4.2 Mbps)) Return Link: Allows: • ~20 kbps for audio: 2 channels (assuming ~ 10 kbps per channel depending on compression used)

			• ~450 kbps for telemetry (operational, crew health and status, situation awareness). Includes telemetry from attached elements • 80+ Mbps Engineering/Science/Video: assume 2 channels 4K video is 32 Mbps, double for margin and add another 16Mbps to account for relay of video for surface assets, etc. • ~1-2 Mbps file transfers, etc. • ~2+ Mbps crew communications (private medical conference, family communications, etc. (audio synchronized with video is ~4.2 Mbps))
Space Vehicle to Moon & Mars Surface Elements (and other Deep Space Destinations)	1-10+ Mbps	5- 25+ Mbps	Forward Link: Allows: • ~20 kbps for audio: 2 channels (assuming ~ 10 kbps per channel depending on compression used) • ~50 kbps for commands • ~25 kbps for Software uploads: Full On-Board SW Upload ~100 Mbps; Assuming 1 hour contact time with and full SW upload in that 1 hour gives ~25 kbps • ~1-2 Mbps for mission planning: (procedures, file transfers, etc.) • ~2+ Mbps Video/imagery: minimum 1 channel 1080p HD @ 2 Mbps, more likely 5Mbps (if 4K, then 8Mbps best case or 16Mbps conservative case)

			• ~2+ Mbps crew communications (relayed) (private medical conference, family communications, etc. (audio synchronized with video is ~4.2 Mbps)) Return Link: Allows: • ~20 kbps for audio: 2 channels (assuming ~ 10 kbps per channel depending on compression used) • ~450 kbps for telemetry (operational, crew health and status, situation awareness). Includes telemetry from attached elements • 16+ Mbps Engineering/Science/Video: assume 1 channels 4K video is 8 Mbps, double for margin. • ~1-2 Mbps file transfers, etc. • ~2+ Mbps crew communications (relayed) (private medical conference, family communications, etc. (audio synchronized with video is ~4.2 Mbps))
Element to Element on Surface of Destination	1- 20+ Mbps (two-way comm)		Exchange: • ~20 kbps for audio: 2 channels (assuming ~ 10 kbps per channel depending on compression used) • ~100 kbps for command and telemetry • ~1-2 Mbps for mission planning: (procedures, file transfers, etc.)

			• ~2+ Mbps Video/imagery: minimum 1 channel 1080p HD @ 2 Mbps, more likely 5Mbps (if 4K, then 8Mbps best case or 16Mbps conservative case)
Space Vehicle and Element in proximity of Space Vehicle such as a resupply vehicle or EVA crewmember	up to 1 Mbps	up to 10 Mbps	Forward Link: Allows: • ~20 kbps for audio: 2 channels (assuming ~ 10 kbps per channel depending on compression used) • ~100 kbps for range, range rate measurements, command, telemetry (in case it needs to be relayed to Earth), etc.; • ~500 kbps for video/images (not necessarily HD or 4K – support GN&C during rendezvous and docking) Return Link: Allows: • ~20 kbps for audio: 2 channels (assuming ~ 10 kbps per channel depending on compression used) • ~450 kbps for telemetry (operational, crew health and status, situation awareness). Includes telemetry from attached elements • 8 Mbps Video: assume 2 channels HD @4Mbps/channel.
Earth and Element on Surface of Moon & Mars (and other Deep Space Destinations)	at least 16 kbps	at least 256 kbps	Forward Link: Allows: • ~10 kbps for audio: 1 channels (assuming ~ 10 kbps per channel depending on compression used) • ~2-6 kbps for commanding Return Link: Allows: • ~10 kbps for audio: 1 channels (assuming ~ 10 kbps per channel depending on compression used)

			• ~240 kbps for telemetry (operational, crew health and status, situation awareness, science etc.).